Design of a High Temperature Steam Generator System using Solar Energy for a Biomass Torrefaction Reactor

by

Syakir Saniy bin Johani

A dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

SEPTEMBER 2011

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CERTIFICATION OF APPROVAL

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Approved by,

(Ir. Dr. Shaharin Anwar Sulaiman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SYAKIR SANIY BIN JOHANI

ABSTRACT

Torrefaction is one of the method to extract biomass energy from its raw form other than direct combustion, thermo chemical transformation, carbonization and others. Torrefaction is a thermal conversion technique for biomass refining process in the oxygen free atmosphere. This process requires atmospheric temperature of 200-300°C. In order to achieve this temperature a necessary outside heat need to be supplied to the torrefaction reactor. This heat can be generated from various sources such as electricity, and hydrocarbon combustion. However the usage of this source consumes some already produced electricity and not environmentally friendly. Apart from all these energy sources, solar thermal energy also could be used as the energy sources for the torrefaction process as it is environmentally friendly and also abundant without the need to use energy in order to extract and use it. The objective of this project is conducted to develop a high temperature solar thermal system for use as an energy source for the torrefaction of biomass. This project focuses developing solar concentrator with tracker, the thermal storage and addition of the existing component including heat exchanger and pump. In order to design the system, a set of weather data for sun irradiation is referred to so that the designed system is not experiencing under design. Solar engineering and heat transfer principles are used in the project. Throughout the phase of the project, the dimension of the system has been finalized and the simulation has been done on the two critical components which are the PTC and the thermal storage tank. The minimum flow rate for HTF for max heat transfer also has been determined.

ACKNOWLEDGEMENT

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ABBREVIATION

HTF	Heat Transfer Fluid
UTP	Universiti Teknologi PETRONAS
PTC	Parabolic Trough Concentrator
TES	Thermal Energy Storage

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Nowadays, the world experiencing energy crisis due to the depletion of hydrocarbon fuel and also the environmental issues aroused due to pollution caused by the combustion of this hydrocarbon fuel. Apart from this non-renewable energy source there are still other potential alternative energy sources that are renewable, carbon lean and also environmentally friendly. Some of the energy are the biomass and solar. In order to bring out the maximum from the biomass, torrefaction process is needed to refine the raw biomass material into solid fuel. This means external energy is needed in order to convert this biomass composition into efficient solid fuel. In order to reduce the usage of produced energy to be used for this process, another raw, cheap, environmentally friendly and abundant source of energy is needed. The interest in manipulating solar energy has already existed from the ancient time and it is one of abundant of renewable energy sources until now. However, only a minuscule fraction of the available solar energy is used. Engineers have continuously sought ways to improve the efficiency of solar energy harnessing by using ever-revolving technologies. This project aim is to develop solar high temperature system that can be used in the biomass torrefaction reactor as shown in the Figure 1.1.

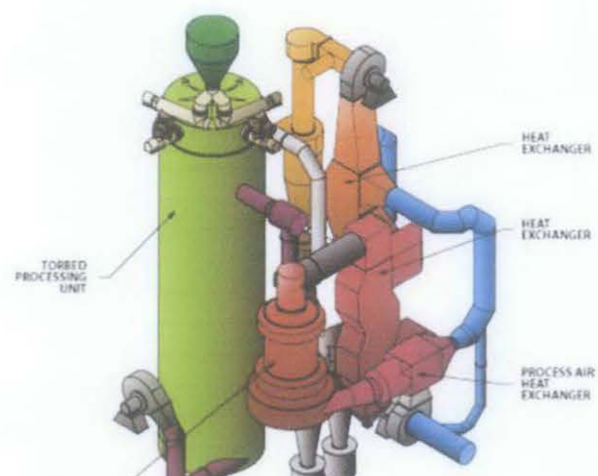


Figure 1.1: A torrefaction reactor (topellenergy.com, 2011)

1.2 Problem Statement

A reactor is going to be developed to process biomass. The process requires heat at 200-280°C which can normally be supplied through electrical heater. Using solar energy, the energy cost for process can be reduced. Solar thermal energy can be converted into various ways. One of the methods is by using solar concentrator to obtain high temperature as high as 400°C (Shuai et al, 2010). The temperature produced will be used to heat up the water until 100°C and the water will be supplied to the reactor to increase the inside temperature of the reactor to 200-280°C.

1.3 Significance of Project

In order to bring out the maximum from the biomass, torrefaction process is needed to refine the raw biomass material into solid fuel. This means external energy is needed in order to convert this biomass composition into efficient solid fuel. The net energy input for torrefaction process is 3000 MJ/Ton of the raw biomass with moisture content of 60% (Shah et al, 2011) equivalent to 65 kg of fossil fuel. In order to reduce the usage of produced energy to be used for this process, another raw, cheap, environmentally friendly and abundant source of energy is needed. The development of this system will help to utilize the solar energy efficiently and reduce the cost of electricity and existing fuel combustion in order to produce torrefied biomass.

1.4 Objectives and Scope of Study

The objectives of this project are to design a solar thermal concentrator that can deliver heat transfer fluid sufficient for the torrefaction. The water will be heated using the heat exchanger to achieve 350°C. Concurrently, this project also is to develop thermal storage system shall be incorporated in order to exploit excess energy and for usage at necessary times such as during night times or rains.

In order to meet the objectives of this project, the following steps were taken:

1. Investigate and analyze the weather data in UTP
2. Determine the size of solar concentrator need to be used
3. Determine the system material, type and of heat exchanger used, size of the pipe, pump specification and HTF flow rate.
4. Auxiliary - design the solar tracker features (mechanical and electrical part).

The scope of study involves research more about the design requirements and material selection for the system. Detailed simulations will be conducted to fully understand the both the requirements and constraints of the system which are the size of the collector, orientation of the concentrator, effect of sun position throughout the day, and htf flow rate. A design concept and its material should be produced by the end of the second semester.

The study is conducted to develop the design and to produce complete technical drawings of the system that are up to the codes of standards. The design should be able to accommodate auxiliary items needed by the system such as bold and nuts, o-ring seal, gasket and solar tracking system. This is expected to be completed by the third semester. Basically, the scope of study for this project can be illustrated in Figure 1.2 which excluding the controlling component. What are shown in the figure are basically to give a concept on how the system will work without putting auxiliary equipment such as valve, flow meter, and the solar tracking mechanism. The pump will operate at constant speed but the HTF flow rate will be varied by using the valve placed after the pump. This applied also for water flow in the heat exchanger. The full description of how the system look like can be referred to the Appendix 5.

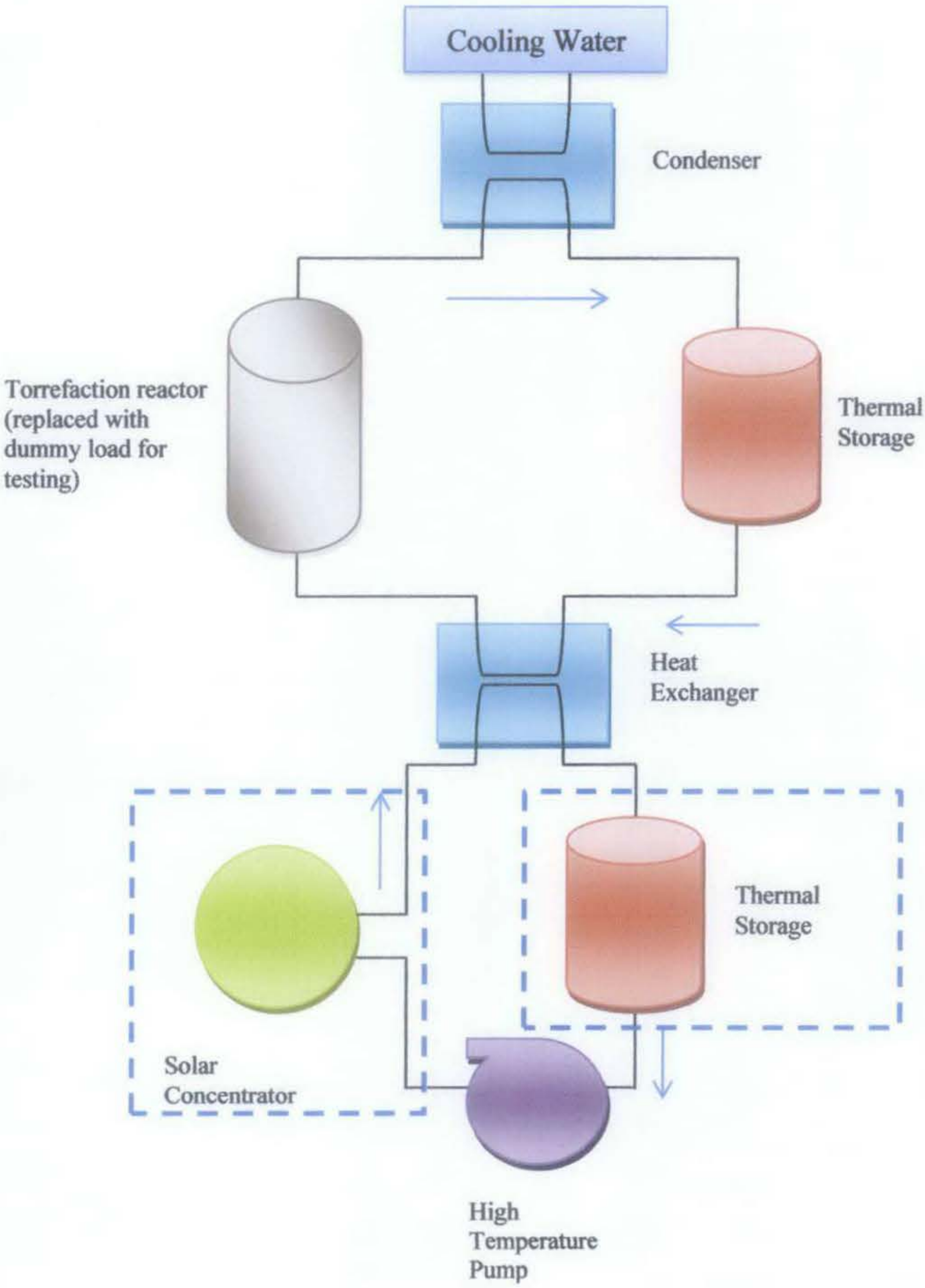


Figure 1.2: Scope of study for the project

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Torrefaction Theory

Torrefaction is a mild pre-treatment of biomass at a temperature between 200-300 °C. During torrefaction the biomass its properties are changed to obtain a much better fuel quality for combustion and gasification applications (Bergman, et al.).

During the process, the biomass loses typically 20% of its mass (dry bone basis – the amount of material that weighs 2400 lbs when it is dry, while only 10% of the energy content in the biomass is lost (SRS, 2011). The comparison between raw and torrefied biomass can be seen in the Table 2.1 (UMU, 2011).

Table 2.1: The comparison between raw and torrefied biomass

No.	Raw Biomass	Torrefied Biomass
1.	Large bulk volume	High density densification
2.	Wet (More than 70% moisture content)	Dry (Less than 15% moisture content)
3.	Expensive grinding cost	Cheap grinding cost
4.	Non-feedable	Feedable
5.	Low energy content (only 30 % of its total energy can be used)	High energy content (90 % of its total energy can be used)
6.	Inhomogeneous	Homogeneous
7.	Risk of bio contamination	No bio contamination

2.2 Thermal Concentrator

Thermal concentrator is a solar collector designed to collect heat by absorbing sunlight. The term is applied to solar hot water panels (flat-plate collector), but may also be used to denote more complex installations such as solar parabolic, solar trough and solar towers or simpler installations such as solar air heat. In this study the focus is to produce temperature higher than possibly delivered by the flat plate collector. Energy delivery temperature can be increased by interposing an optical device between the source of radiation and the energy absorbing surface absorbing surface (Duffie, Beckman, 1991). The approach can be used for the concentrators are imaging (lenses) and non imaging (heliostat or reflector). Solar tracking integration are also are made possible to increase the efficiency of collecting solar radiation. Solar concentrator commonly consists of reflector and optical system.

Some consideration needs to be taken care of are the concentration ratio which is the ratio of area aperture and the area of receiver which shown in the Figure 2.1.

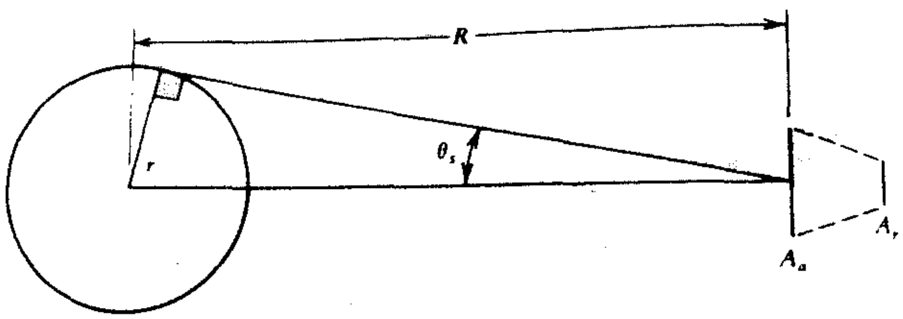


Figure 2.1: Schematic of sun at Ts at R distance from a concentrator with aperture area A_a and receiver area A_r

where $\boldsymbol{A_a}$ is aperture area, $\boldsymbol{A_r}$ is receiver area, R is aperture distance from sun, r is sun radius and θ_s is sun angle.

Concentration Ratio, $C = \frac{A_a}{A_r}$ (2.1)

The ratio has the upper limit which gives the maximum concentration ratio depend whether it is a three-dimensional concentrator or two-dimensional concentrator. In this study the development of the system will be on three-dimensional concentrator which given by the following equation which is

$$\left(\frac{A_a}{A_r}\right)_{circular,max} = \frac{R^2}{r^2} = \frac{1}{\sin^2\theta_s} \tag{2.2}$$

This ratio will be used to compare the concentration of each type of concentrator.

2.3 Dewar Tube

A glass vessel used for keeping liquids at temperatures differing from that of the surrounding air. This is done by reducing to a minimum the transfer of heat between the liquid and the air. A Dewar flask consists of a double-walled flask, with the space between the two walls exhausted to a very high vacuum, to minimize transfer of heat by convection and conduction. The inner surfaces of the walls are silvered to reduce transfer of heat by radiation; areas of contact between the two walls are kept at a minimum to keep down conduction of heat (Daviddarling, 2011). The principle of this tube will be used for thermal storage and solar receiver of the solar concentrator system.

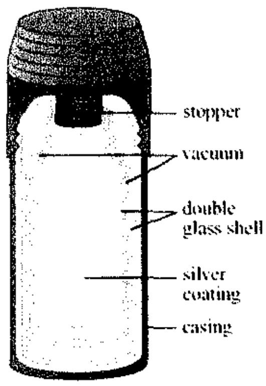


Figure 2.2: Vacuum flask (Dewar tube) diagram (Wikipedia, 2011)

2.4 Solar Tracker

A solar tracker is a generic term used to describe devices that orient various payloads toward the sun (Wikipedia, 2011). Payloads can be photovoltaic panels, reflectors, lenses or other optical devices. In this study which focused on concentrated solar thermal (CSP) applications trackers are used to enable the optical components in the systems. The optics in concentrated solar applications accepts the direct component of sunlight light and therefore must be oriented appropriately to collect energy. Tracking systems must be integrated in almost all solar collector system applications because such systems do not produce much energy unless oriented closely toward the sun.

2.5 Centrifugal Pump

A centrifugal pump is a rotodynamic pump that uses a rotating impeller to increase the pressure of a fluid (Johani et al, 2011). It is commonly used to move fluid through a piping system. The fluid enters the pump impeller along and near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits into the downstream piping system. Centrifugal pumps are used for large discharge through smaller heads.

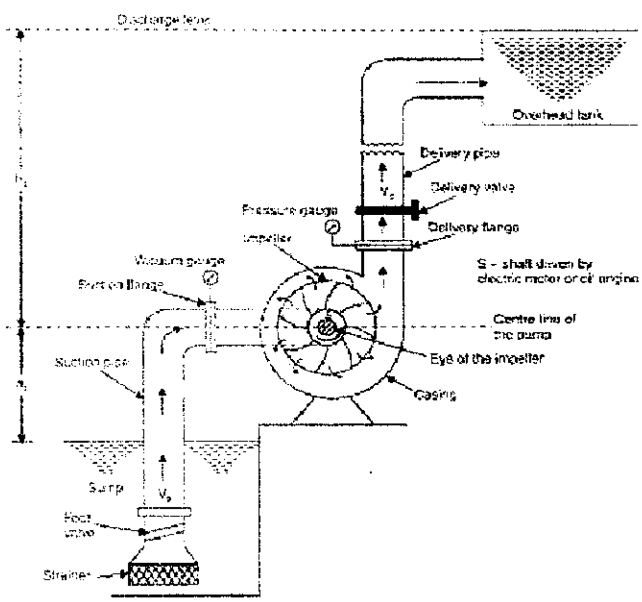


Figure 2.3: Common usage of pump in the industry. See Figure 2.4 (Johani et al, 2011)

Based on the figure 2.3, it shown the mechanism of the pump in a system where, the pump is used to pump and lifted up the fluid upwards to the system. Literature defines that centrifugal pump is the highest efficiency pump as to compare with others; cantilever pump. Theoretically, reducing the head from the head on a centrifugal pump will decrease the flow of the fluid and hence increase the power demand.

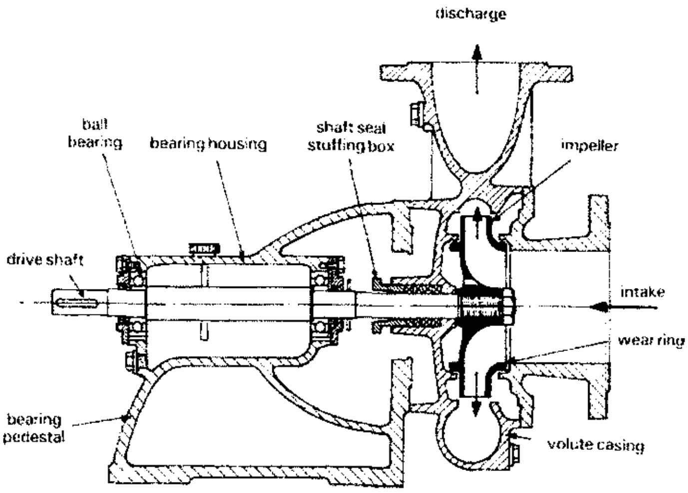


Figure 2.4 : The overall design and equipments in a centrifugal pump (Johani et al, 2011)

There is various kind of design of centrifugal pump which all of them share the same concept to pump the water upwards. The most important part of the centrifugal pumps is the impeller, which used to suck the fluid to be lifted upwards and the inlet and outlet gateway. Basic design of a pump is that, it should be lifted up the water upwards at the outlet gate where the water must come in the inlet gateway radially. Like most pumps, a centrifugal pumps convert's mechanical energy from a motor to energy of a moving fluid; some of them go into kinetic energy of fluid motion and some into potential energy which representing lifting up the fluid against the gravity to a higher level. Most of the energy conversion is due to the outward force that curved impeller blades impart on the fluid

Centrifugal pumps work by converting the kinetic energy of a liquid into pressure energy. It does this by means of two major components; for example the impeller and the diffuser. Fluid entering a centrifugal pump is immediately directed to the low pressure area at the center or eye of the impeller and as the impeller is rotated by means of a motor or engine, a low pressure region is created at the impeller eye causing the liquid to be sucked into the eye. As the impeller rotates, they transfer momentum to incoming fluid and sucked fluid is thrown out with force through the periphery of the impeller. A transfer of momentum to the moving fluid increases the fluid's velocity. As the fluid's velocity increases its kinetic energy also increases. Now, the diffuser comes into action. The diffuser due to its shape of varying cross-sectional area causes the liquid to slow down and from Bernoulli's principle; a reduction in kinetic head will be compensated by an increase in pressure head. This pump will be used to pump the HTF across the system.

2.6 Heat Exchanger

Heat exchanger are the device that's that facilitate the exchange of heat between two fluids that are at different temperature while keeping form mixing with each other. Heat exchangers are commonly used in wide range of application from heating to air conditioning. The heat transfer in heat exchanger usually involves conduction through wall separating the two fluid and convection between the fluid . The most common type of heat exchanger to beused are shell and tube heat exchanger shown in Figure 2.5 (Cengel, 2006). The heat exchanger will be used in this project in order to transfer the heat from the solar concentrator to the working fluid in the reactor.

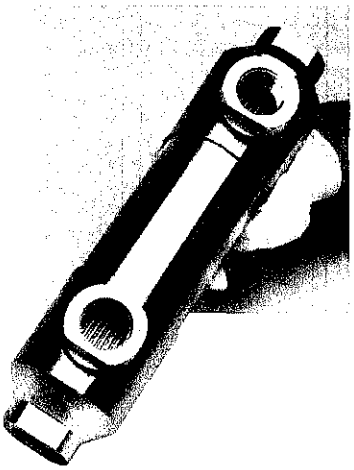


Figure 2.5 : The shell and tube heat exchanger (Exergyllc, 2011)

2.7 Theory and Calculation

The solar concentrating system which has to be designed must be able to comform the weather condition and irradiation in the site which is Malaysia. The design is been shown in the Figure 1.2. In this section, the method of calculating the parameter until the project progress until now involves in the system will be discussed here.

2.7.1 Irradiance Measurement

The irradiance measurement is important as the average reading will determine the size of the system especially the solar concentrator. The type, size and shape of the solar concentrator will determine the amount of heat it can be transferred. The solar radiation on clear days can be calculated using the equation (2.3). The diffuse radiation also can be used on the solar concentrator as it is gather around it during sunny day.

$$I_h = I_{b,h} + I_{d,h} \tag{2.3}$$

where I_h is the total instantaneous radiation on horizontal surface, $I_{b,h}$ is the value of direct radiation in W/m^2 and $I_{d,h}$ is Diffuse radiation in W/m^2.

The role of value is shown in the Figure 2.6 below

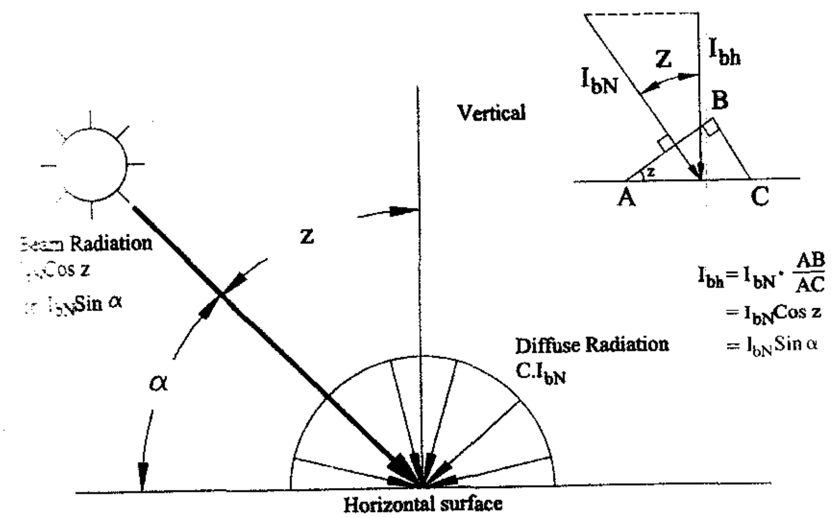


Figure 2.6 : Solar radiation on horizontal surface

2.7.2 Receiver and HTF Selection

Since the receiver is ready made, the selection has been done based on the power rating of the collector and the flow rate of HTF. The size of the receiver is fixed and can only be varies by the absorber tube and the length of the receiver itself. The HTF will be selected based several criteria such as, specific capacity, vapor pressure and its boiling point.

2.7.3 Heat Exchanger Selection

Since the receiver is ready made, the selection has been done based on the power rating of the collector and the flow rate of HTF. The size of the receiver is fixed and can only be varies by the absorber tube and the length of the receiver itself.

2.7.4 Thermal Storage Design

The size of the storage depends on the flow rate of the HTF and total volume of the HTF can be heated during the operation of the solar concentrator with the specified receiver size. The storage tank will be design as smallest as it can be to conform to the miniature scale objective and to reduce the space govern by the end product.

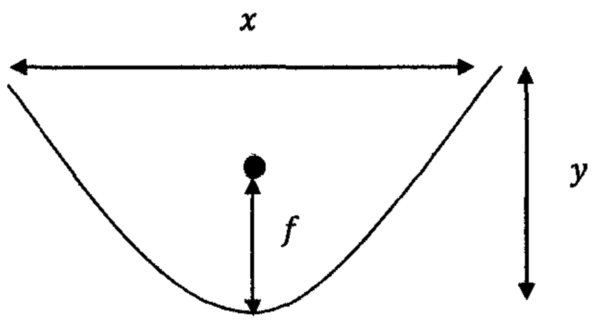
2.7.5 Solar Concentrator Design

The solar concentrator design is based on parabola with the principle equation (2.4). Through this equation the focus point of the parabolic/ parabloid concentrator can be determined.

$$y = \frac{x^2}{4f} \tag{2.3}$$

where y is the depth of the parabola, x is the diameter/ opening of the parabola and f is equal the focus of the parabola

The role of value is shown in the Figure 2.7



LEGEND

x = diameter of parabola
y = depth of parabola
f = focus of the parabola

Figure 2.7 : Parabolic surface denomination

2.7.6 Equipment Sizing

In sizing the equipment of the system, there are some equations used. The equations in determining equipment sizing are shown in Table 2.1.

Table 2.1: Equation for Equipment Sizing (aip.org, 2011)

No.	PARAMETER	EQUATION
1)	Heat Transferred	*Q = mass flow rate x liquid specific heat x temperature difference.*
2)	Pipe Cross-sectional Area	A = Π x (radius)² or Π x (Diameter/2)²
3)	Fluid Velocity	*V = (Flow rates)* / (Pipe cross sectional area)
4)	Reynolds Number	$\text{Re} = \dfrac{\text{Density x Pipe ID x Velocity}}{\text{viscosity}}$
5)	Friction Loss in 100 m length of pipe	$\Delta P/100\text{ft} = (0.00115)\ \dfrac{\text{Moody friction factor x liquid flow rate}^2 \text{ x SG}}{\text{Pipe ID}^5}$
6)	Total pressure drop	P = Friction Loss per 100m x equivalent length

In sizing the pipe, some graph and table are used for determining the moody friction factor and equivalent length of pipe. They are chart for relative roughness, moody friction factor chart and equivalent table.

2.7.7 Fluid Flow Justification

There are two types of flow - turbulent or laminar (aip.org, 2011). Turbulent flow produces better heat transfer, because it mixes the fluid. Laminar-flow heat transfer relies entirely on the thermal conductivity of the fluid to transfer heat from inside a stream to a heat exchanger wall. An exchanger's fluid flow can be determined from its Reynolds number (Re) where is flow velocity and D is the diameter of the tube in which the fluid flows. The units cancel each other, making the Reynolds number dimensionless. If the Reynolds number is less than 2,000, the fluid flow will be laminar; if the Reynolds number is greater than 6,000, the fluid flow will be fully turbulent. The transition region between laminar and turbulent flow produces rapidly increasing thermal performance as the Reynolds number increases. The type of flow determines how much pressure a fluid loses as it moves through a heat exchanger. This is important because higher pressure drops require more pumping power. It is useful to predict the pressure drops that can occur with changing rates of flow. Laminar flow produces the smallest loss, which increases linearly with flow velocity. For example, doubling the flow velocity doubles the pressure loss.

2.7.8 Number of Transfer Units for Counter Flow Heat Exchanger

Effectiveness relation of the heat exchangers typically involve the dimensionless group of UAs/$C_{min.}$ This quantity is called the number of transfer units NTU and is expressed as Equation (2.4).

$$\mathrm{NTU} = \frac{UA_s}{C_{min}} = \frac{UA_s}{(\dot{m}c_p)_{min}} \tag{2.4}$$

where U is the overall heat transfer coefficient and A_s is the heat transfer surface area of the heat exchanger. It is also convenient to define another dimensionless quantity of capacity ratio, c as:

$$c = \frac{C_{min}}{C_{max}} \tag{2.5}$$

It can be shown that the effectiveness of the heat exchanger is a function of NTU and c and for the counter flow heat exchanger arrangement, the effectiveness, ε of the heat exchanger can be related as:

$$\varepsilon = \frac{1-\exp[-\mathrm{NTU}(1-c)]}{1-c\exp[-\mathrm{NTU}(1-c)]} \tag{2.6}$$

CHAPTER 3
METHODOLOGY

3.1 Methodology Flow-Chart

The methodology flow chart is shown in the Figure 3.1.

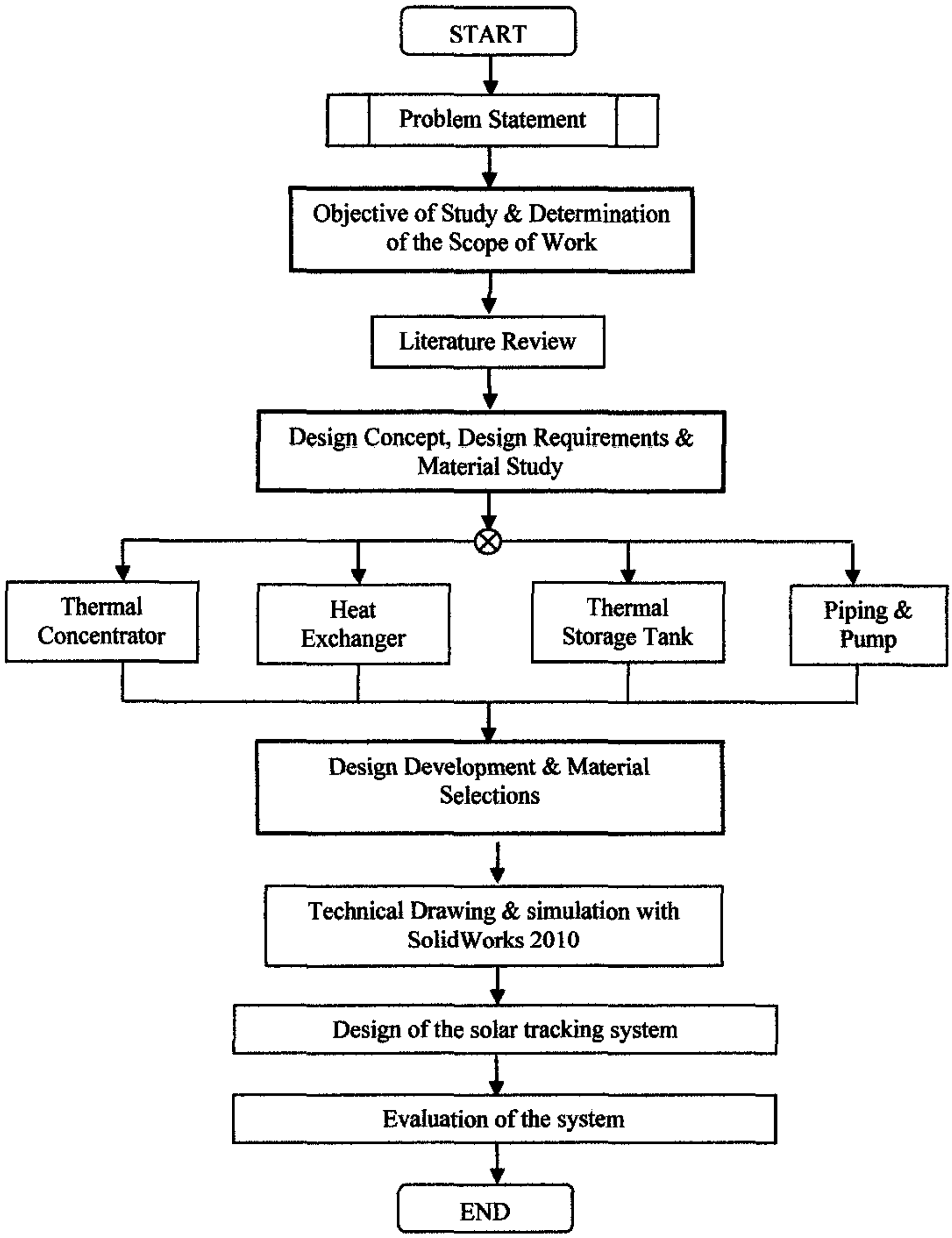


Figure 3.1: Process flow chart

3.2 Project Activities and Gannt Chart

For the project activities, Please refer to the Appendices section for the Appendix 1: Gantt chart for Second Semester (May 2011) and Appendix 2: Gantt chart for Third Semester (September 2011). For the first semester the project is focused on the rough design, material selection and equipment sizing while during second semester the project focused on detail design and analysis of part of the system components.

3.3 Detailed Descriptions of Important Activities

a) ***Preliminary Study & Determination of the Scope of Work***

Before starting the project, a preliminary study will give the author a better understanding of the topic. Information will be gathered from journals, books, newspapers, and also case studies that have any relevance to the topic. Study on previous designs will provide valuable information on the functions of the explosion vessels that can be used in planning the project and understanding its scope of work.

b) ***Design Concept, Design Requirements & Material Study***

Design requirements are sets from the prior analysis on the heat transfer from the concentrator to the vacuum insulated vessel and design constraints set by the Supervisor will serve as a guideline in the creation of the design concept and material study. The weather data are measured in UTP for several months for this purpose in order to make the design optimized for the system to be tested in this location if it were to be fabricated.

c) ***Design Development & Material Selections***

Development and refinement of design concept are needed to ensure the design meeting the safety standards and the previously agreed design requirements. A few design concept should be created and finalize through a decision matrix technique.

An established design concept will then allow for a material selections process also to be done through the decision matrix technique.

d) ***Technical Drawings and simulation with SolidWorks 2010***

Technical drawings of the final product should be created through the SolidWorks simulation software that complies with ASME (American Society of Mechanical Engineers) codes and regulations for solar engineering. The express finite element simulation will be done through this software also in order to determine the structural and thermal reliability of the system. The thermal and stress analysis will be run using the Solidworks Simulation.

e) ***Design of solar tracking system***

The solar tracking will be designed along the development of the solar concentrator whether it will be manual handling or motor assisted with electronic control.

3.4 Tools and Equipment Required

a) Hardware

1) Data Logger

This hardware is used in order to record the weather data of the location which the system is planning to be tested if the design were to be fabricated. The weather data measurements is taken in the 5-minute interval for several months and the resulted data will be evaluated as the input for the design.

b) Software

1) SolidWorks 2010 Premium

SolidWorks is a 2D and 3D CAD (Computer Aided Design or Computer Aided Drafting) and simulation software application used in architecture, construction and manufacturing to assist in the preparation of blueprints and other engineering plans. In this study this software will be used to create technical drawing and to conduct simulation on the virtual prototype.

2) Eagle 5.7.0 Professional

This software is used to design a circuit and simulate it for PCB fabrication for solar tracking system control and timing. The circuit will be done prior to the completion of the solar concentrator and the storage vessel.

3) Parabolic Calculator

This software is used to design a parabolic profile and simulate it for PCB fabrication for solar tracking system control and timing. The base equation for this parabolic profile modeling is as per stated in the Equation 2.3.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Solar Radiation Evaluation at UTP

Table 4.1 shows the results of irradiation recorded in UTP for the past three month (June, July, August) 2011. This result is needed as a vital parameter for designing the solar concentrator. This data have been collected by Khairul Nazmi Ahmad Majdi but concentrating on different parameters for the project entitles "Performance Improvement of Photovoltaic Panels Through Mitigation of Surface Temperature Cooling and Debris Removal" supervise by Ir Dr Mohd Shiraz Aris. The reading taken for 12 hour operation starting from 7am to 7pm with the time tolerance of ±30 minutes. The data taken for every 5 minutes interval.

Table 4.1: Average Irradiation tabulation for UTP

No	Date taken	Average Irradiation (W/m^2)
1	22/6/2011	426
2	29/6/2011	476
3	30/6/2011	437
4	27/7/2011	321
5	10/8/2011	408
6	11/8/2011	519
7	12/8/2011	395
8	13/8/2011	1031
Total average		**493**

The graphical representation of the can be seen in the Appendix 3.Using the equation 2.3 and Figure 4.6 the values that are known are :

a. Direct radiation, $I_{b,h} = 493$ W/m^2

b. Altitude angle, α = 85° (solarelectricityhandbook.com,2011)

c. From the Equation 2.3 it is known that

$$I_{bN} = \frac{I_{b,h}}{\sin \alpha}$$

$$= 495 \text{ W/m}^2$$

To find diffuse radiation, $I_{d,h}$

$$I_{d,h} = C.I_{bN}$$

where C = Skydiffuse factor = 0.122 (from Table 4.2)

Table 4.2: Average value of atmospheric optical depth (k) and sky diffuse factor C for 21st day of each month, for average atmospheric conditions at sea level

Month	1	2	3	4	5	6	7	8	9	10	11	12
k	0.142	0.144	0.156	0.180	0.196	0.205	0.207	0.201	0.177	0.160	0.149	0.142
C	0.058	0.060	0.071	0.097	0.121	0.134	0.136	0.122	0.092	0.073	0.063	0.057

Source: Threlkeld, J.L. and Jordan, R.C., *ASRAE Trans.*, 64:45 (1958) [76].

$$I_{d,h} = (0.122)(495)$$
$$= 60.39 \text{ W/m}^2$$

thus giving the total irradiation value of

$$I_h = 495 + 60.39$$
$$= 555 \text{W/m}^2.$$

This total radiation is just as half of the radiation reading of standard 1000 W/m^2 gives the solar concentrator an under design if it is usually design and use according to the norm. To suits the weather here it is proposed that to- be designed solar concentrator will be having two time of it usual size for the same purpose in Malaysia specifically in UTP in order to supply the same power.

4.2 The Concentrator and Receiver Design

Before starting the design process, the shape of the concentrator itself plays a major role in the concentrator design. The objective of this process is to choose the most suitable shape for the concentrator that can supply more power to the HTF and also can supply heat to the HTF in large quantity in one time. Since smallest existing receiver tube in the market will be used, the compatibility issues with the designed concentrator also must be taken into consideration. A common selection method in designing is the selection matrix technique, which are used in this research. The shape of the concentrator are mainly selected from the common type of concentrator that are used in solar power plant based on Principles of Solar Engineering (Goswami et al, 2000)

Table 4.3: Shape selection matrix for solar concentrator

Criterion	**Weight**	**Parabolic Trough Concentrator**	**Parabloid Concentrator**
High power concentration given the same area coverage	4	4 x 4 =16	3x 4 =12
Large heat transfer area	4	3 x 4 =12	2 x 4 =8
Compatibiltiy with existing receiver	4	4 x 4 =16	1 x 4 =4
Machinability Index (Ease to Fabricate)	2	3 x 2 =6	2 x 2 =4
TOTAL		50	28

Rating:

5 = High
4 = Medium-High
3 = Medium
2 = Medium-Low
1 = Low

Based on Table 4.3, the solar concentrator shape to be selected is the parabolic trough concentrator as it supplies more power given the same area coverage and has large heat transfer area between the receiver and much easier to be fabricated compared to parabloid concentrator.

4.3 Material Selection

The materials selection process for the concentrating surface need to be conducted. The objective of this process is to choose the most suitable materials for the concentrating surface so that the most sun radiation will be successfully directed to the receiver tube. The suitable material for thermal storage also needs to be decided. The Selection matrix is as shown in Table 4.4.

Table 4.4: Material selection matrix for solar concentrator surface

Criterion	**Weight**	**Aluminum**	**Aluminum with reflective coating (Refletech)**	**Stainless Steel**
Reflective index	4	3 x 4 =12	5x 4 =20	3x 4 =12
Price	2	4 x 4 =16	3 x 4 =12	2x 4 =8
Ease to clean	3	3 x 4 =12	4 x 4 =16	3x 4 =12
Ability to withstand changing weather	3	3 x 4 =16	4 x 4 =16	4x 4 =12
Machinability Index (Ease to Fabricate)	4	3 x 4 =12	3 x 4 =12	1x 4 =4
High temperature operation (60°C)	4	5x 4 =6	3 x 4 =12	5x 4 =20
TOTAL		74	**88**	**68**

Rating:
5 = High
4 = Medium-High
3 = Medium
2 = Medium-Low
1 = Low

The selection matrix for the thermal storage is shown in Table 4.5.

Table 4.5: Material selection matrix for thermal storage tank

Criterion	Weight	Stainless Steel 316 (Annealed Plate)	Low Carbon Steel	Aluminium Alloy 6061 T6
Ability to withstand high temperature (Coeficient of thermal expansion)	4	3 x 4 =12	4 x 4 =16	1 x 4 =4
Ability to withstand fracture (hardness)	3	4 x 3 =12	3 x 3 =9	1 x 3 =3
Ability to withstand corrosion	3	5 x 3 =15	1 x 3 =3	5 x 3 =15
Machinability Index (Ease to Fabricate)	2	3 x 2 =6	5 x 2 =10	5 x 2 =10
Weldability	2	5 x 2 =10	5 x 2 = 10	5 x 2 = 10
Price	2	3 x 2 =6	5 x 2 = 10	5 x 2 =10
TOTAL		61	58	57

Rating:
5 = High
4 = Medium-High
3 = Medium
2 = Medium-Low
1 = Low

From Table 4.4 and Table 4.5, the best materials for the solar concentrator surface is the aluminum sheet and the thermal storage body is stainless steel 316 (annealed plate) respectively.

4.4 Concentrator Surface Profile Design

The parabolic surface profile on the parabolic trough is designed basically on certain parabolic equation given as Equation 2.3 (ASME Solar Engineering Journal, 2001). Some criterion taken into consideration while designing the profile is the ease of fabrication of the parabolic surface itself. Which means the diameter value and the depth of the parabolic surface must generate a reasonable and achievable focal point. The size of the profile must double the standard concentrator for the smallest evacuated receiver tube. Using Parabola Calculator Software, the input was inserted using trial and error method as shown in the Figure 4.1. Since only integer number is acceptable 24 is equal to 2.4 m.

Figure 4.1 Usage of parabola calculator to determine the parabola dimension for 16 segments

After trial and error input, the value that came in conclusion is summarized in the Table 4.6.

Table 4.6 Parabolic Surface Profile Detail

Parabola Dimensions	**Value (m)**
Diameter, x	2.4
Depth, y	0.6
Focus, f	0.6

4.5 The Concentrator and Pipe Sizing and Insulation

The parabolic trough concentrator size is made basically based on the smallest existing evacuated tube in the market since it is difficult to customize evacuated tube size apart from its length. Tehe evacuated tube specification is shown in the Figure 4.2. The specification of the parabolic concentrator surface can be shown in Figure 4.3 at the trough length 2.6 m. Using the features available in the Solidworks 2010, the reflecting surface of the parabolic trough concentrator is calculated.

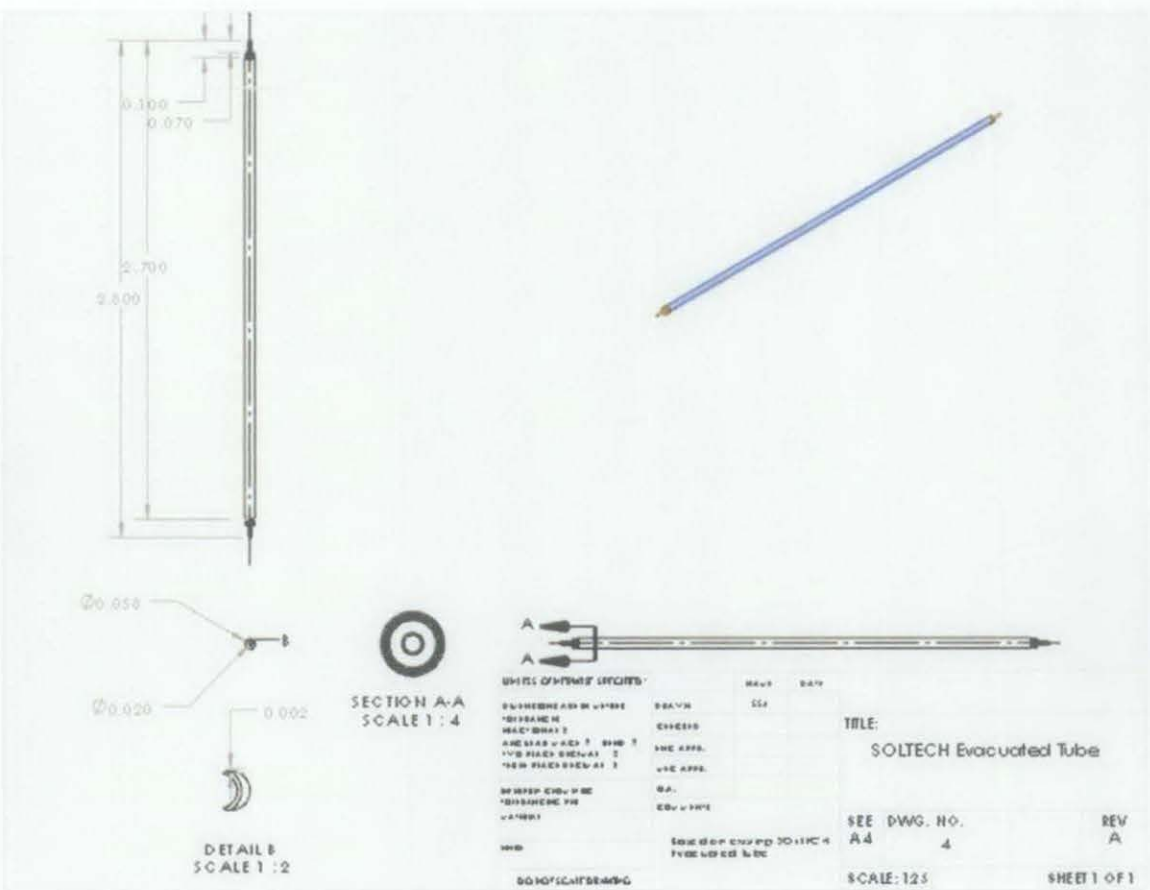


Figure 4.2 The dimension of the evacuated tube of PTC receiver

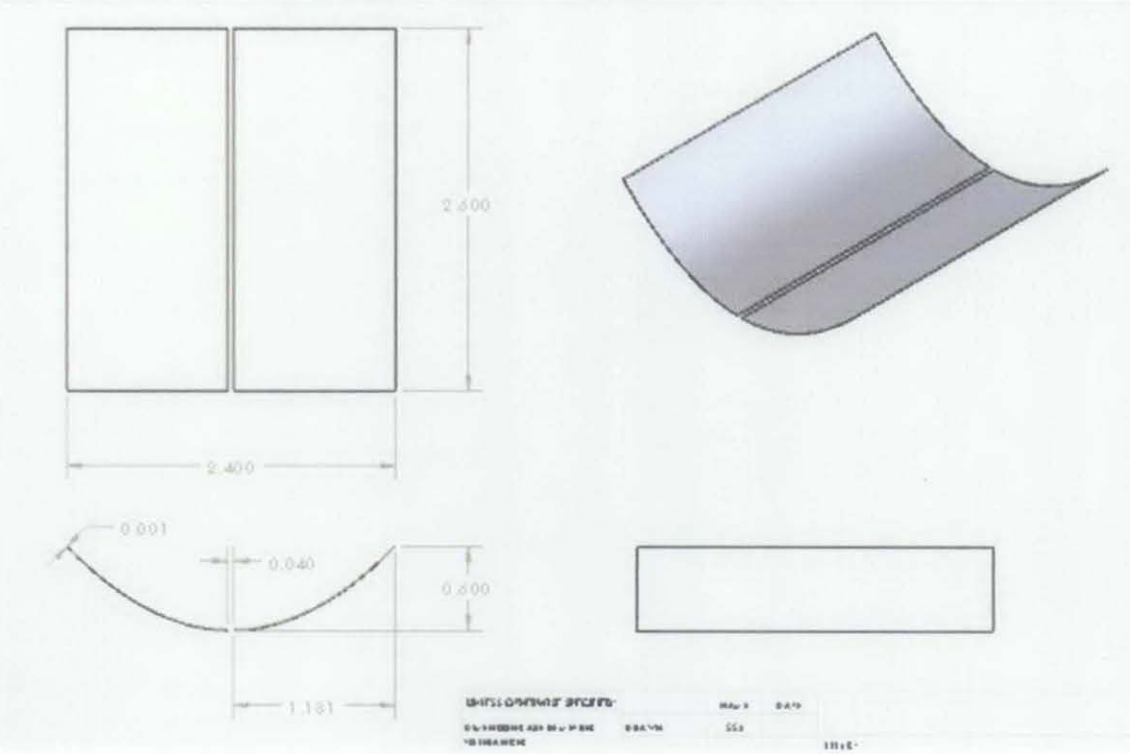


Figure 4.3 The dimension of the parabolic surface of the PTC

Using the features available in the Solidworks 2010, the reflecting surface of the parabolic trough concentrator is calculated after setting aside the gap for the drainage purpose during rainy days. The value stated is shown in the Figure 4.3. The reflective surface area totaled to be 7.06 m^2. Given the value of total radiation in UTP of 555 W/m^2, the parabolic surface roughly have a power rating of 3918 Watt assuming radiation is 100 percent reflected to the receiver.

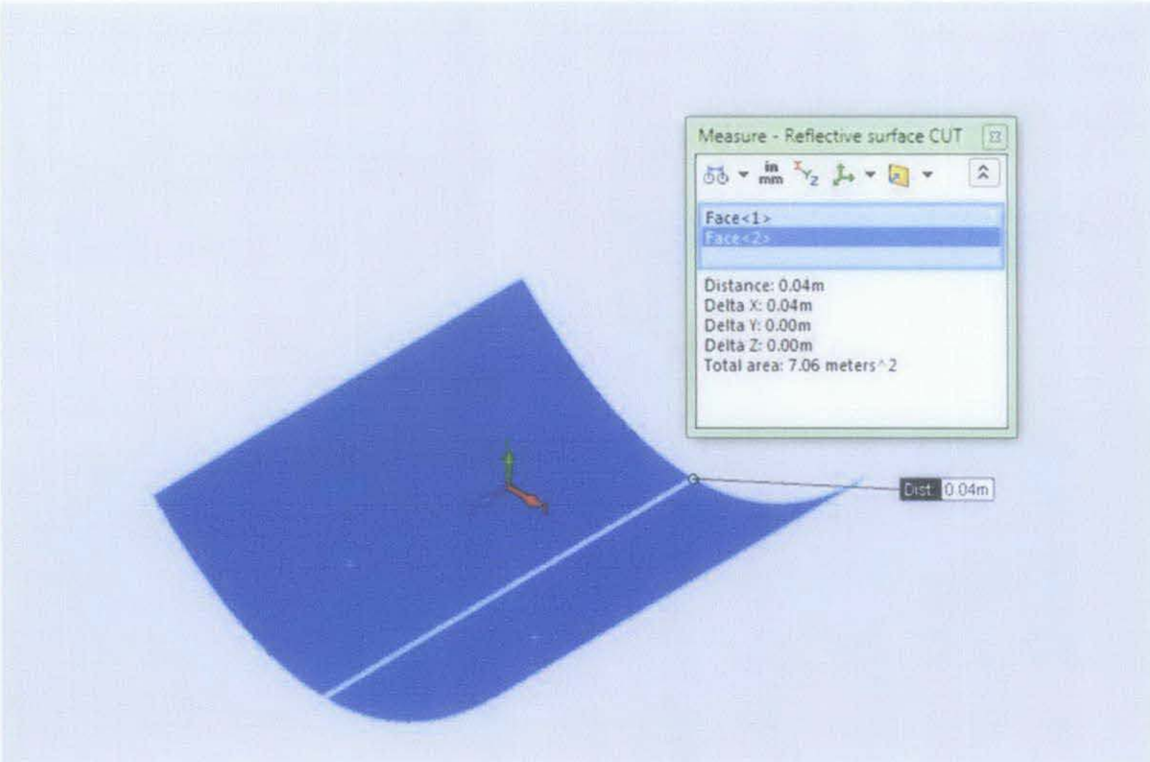


Figure 4.4 The dimension of the parabolic surface area of the PTC

The proposed sizing of the system is conducted based on the smallest pipe possible for the receiver tube requirement. Stainless steel pipe will be used as the pipe line in the system as it has lower thermal conductivity; the 20 mm stainless steel pipe is selected after considering the size of thermal storage and economic aspect. The insulation of the pipe is ceramic fiber with the thickness of 7 mm.

4.6 The Heat Transfer Fluid Selection

The heat transfer fluid will be used to transport the heat from the receiver tube medium selection process for the concentrating surface need to be conducted. The objective of this process is to choose the most suitable medium for the transferring from the collector to the heat exchanger and can be stored without changing it phase that can lead to high vapor pressure in the pipe line of the system. The Selection matrix is as shown in Table 4.7.

Table 4.7: Medium selection matrix for PTC HTF to the storage tank

Criterion	Weight	Water	Dowtherm A	Therminol-72
High temperature operation without changing phase	5	2 x 5 =10	3x 4 =12	4x 4 =16
Vapor pressure	4	1x 4 =4	4 x 4 =16	5x 4 =20
Specific Heat	3	4 x 3 =16	3 x 3 =9	3x 3 =9
Thermal conductivity	3	4 x 3 =12	3 x 3 =9	3x 3 =9
Price	2	4 x 2 =8	3 x 2 =6	3x 2 =6
TOTAL		50	52	60

Rating:
5 = High
4 = Medium-High
3 = Medium
2 = Medium-Low
1 = Low

From the selection matrix, it is finalized that the most suitable HTF for the concentrator is the Therminol-72. The properties of the all HTF can be referred in Appendix 4.

4.7 The Thermal Storage Tank

The thermal storage tank functioned to retain the heat collected by HTF at the solar concentrator for as long as it can especially during night and rainy days so that the heat can be continuously transferred to the heat exchanger for a certain periods of time. The main material selection matrix for the HTF container is as shown as Table 4.8.

Table 4.8: Material selection matrix for HTF storage tank

Criterion	Weight	Stainless Steel 316 L	Low Carbon Steel	Aluminium Alloy 6061 T6
Ability to withstand high temperature (Coeficient of thermal expansion)	4	3 x 4 =12	4 x 4 =16	1 x 4 =4
Ability to withstand fracture (hardness)	3	4 x 3 =12	3 x 3 =9	1 x 3 =3
Ability to withstand corrosion	3	5 x 3 =15	1 x 3 =3	5 x 3 =15
Machinability Index (Ease to Fabricate)	2	3 x 2 =6	5 x 2 =10	5 x 2 =10
Weldability	2	5 x 2 =10	5 x 2 = 10	5 x 2 = 10
TOTAL		55	48	42

Rating:
5 = High
4 = Medium-High
3 = Medium
2 = Medium-Low
1 = Low

From the selection matrix, it is finalized that the most suitable material for the storage containers is the Stainless Steel 316 L The properties of the all material can be referred in Appendix 4.

4.8 The Heat Exchanger

The heat exchanger is selected based on the existing specification and just been chose based on sizing and estimation. The specification of the heat exchanger is selected as Exergy Model No.0604 and can be viewed in the Appendix 7.

4.9 System Design

In this project, the draft designs of the product and its components are produced using Solidworks 2010 Premium. The 3D drawing is useful in determining whether the components will fit each other perfectly. Drawing in in this software allowed for detailing such as fasteners selection, threading and simple assembly simulation. Using this software, some simulation can be done such as the thermal analysis on the concentrator and stress analysis on the thermal storage wall due to existence of evacuated layer. The simulation run on the component assemblies as one of the method to reveal any fault in the design thus allowing for corrective actions to be made on the draft in Solidworks. Figures 4.5 to 4.13 show the detail design of the main component of the system.

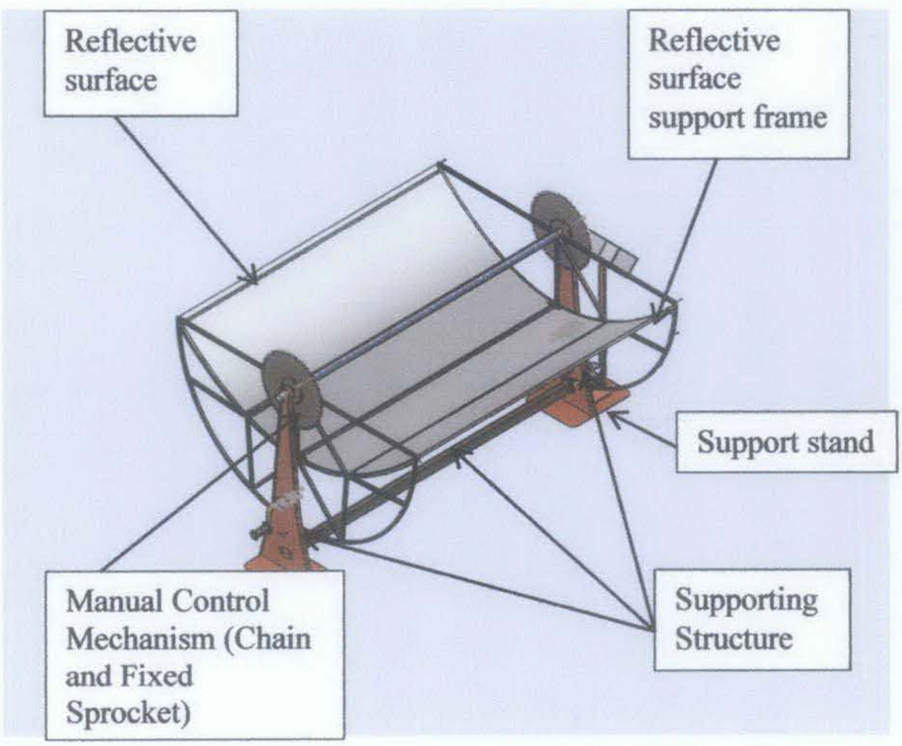


Figure 4.5 The structure of PTC (manual control at the front)

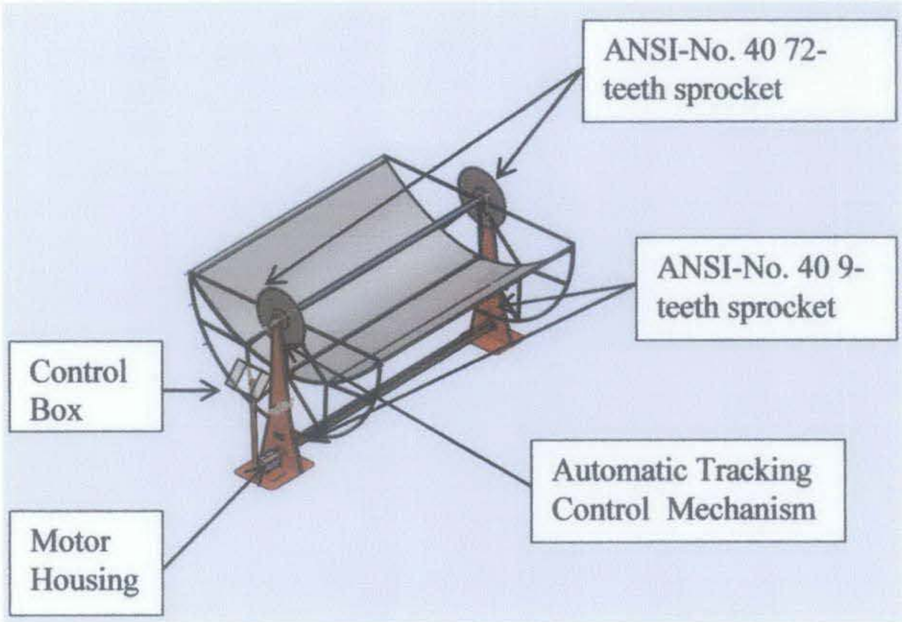


Figure 4.6 The structure of PTC (automatic control at the front)

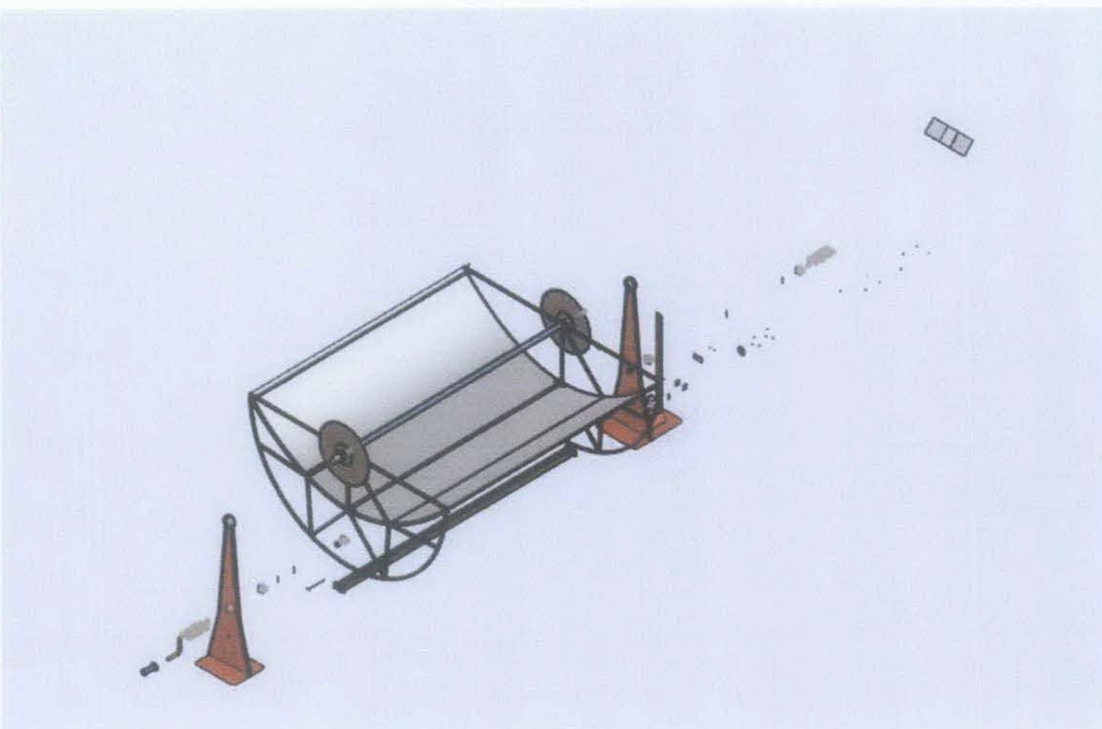


Figure 4.7 Break-up of the components

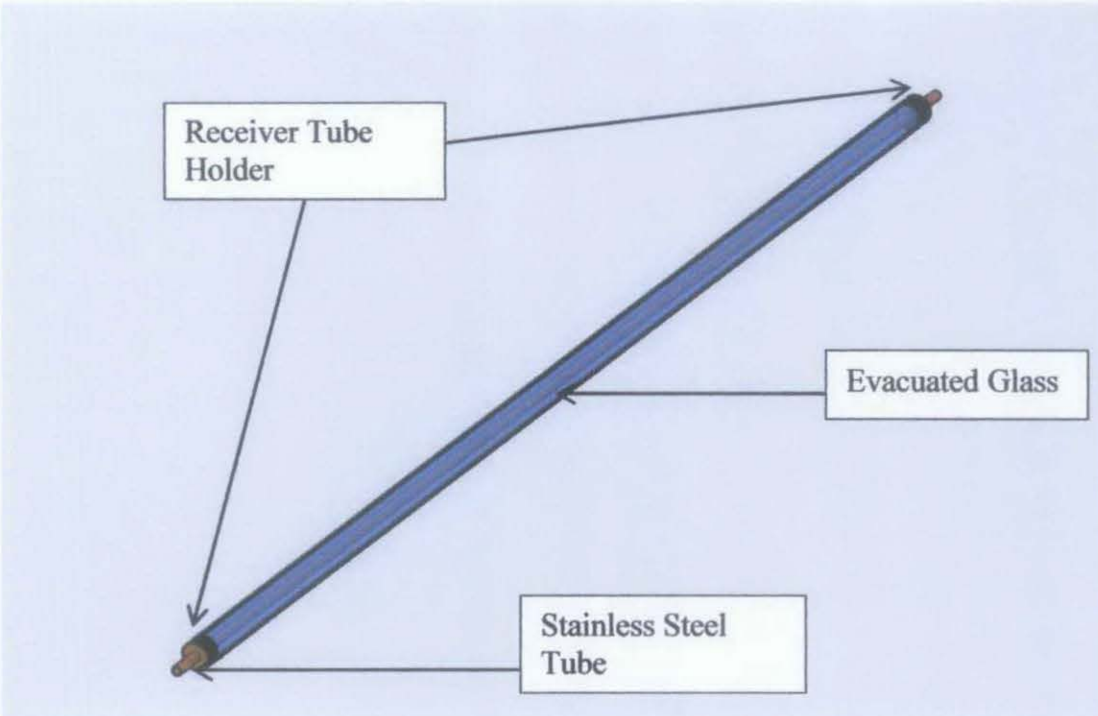


Figure 4.8 Evacuated receiver tube

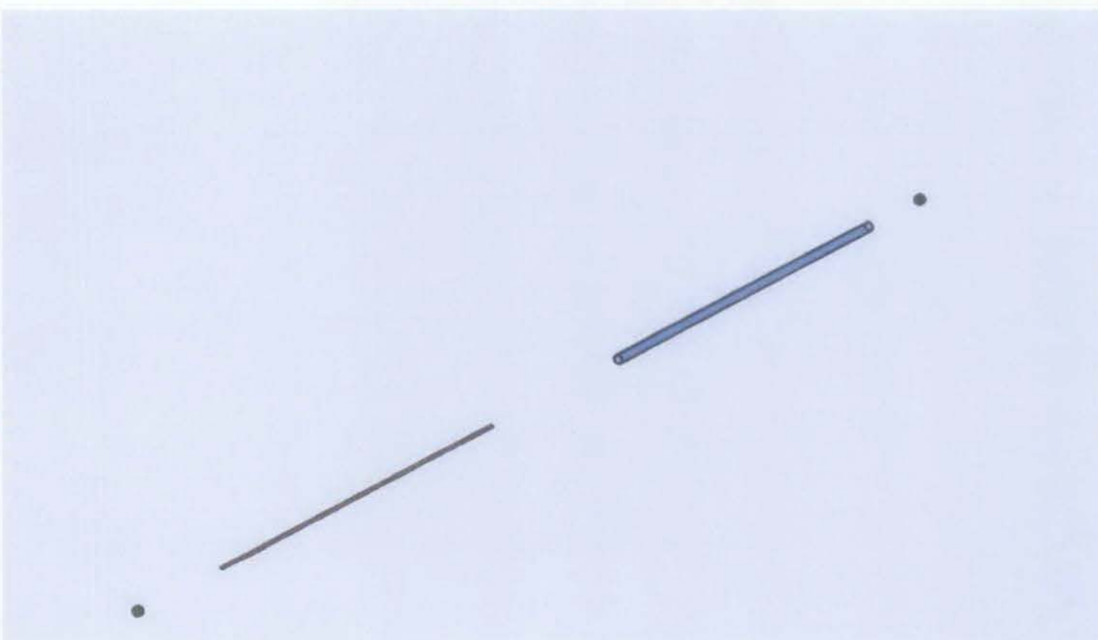


Figure 4.9 Break-up of the Evacuated Tube

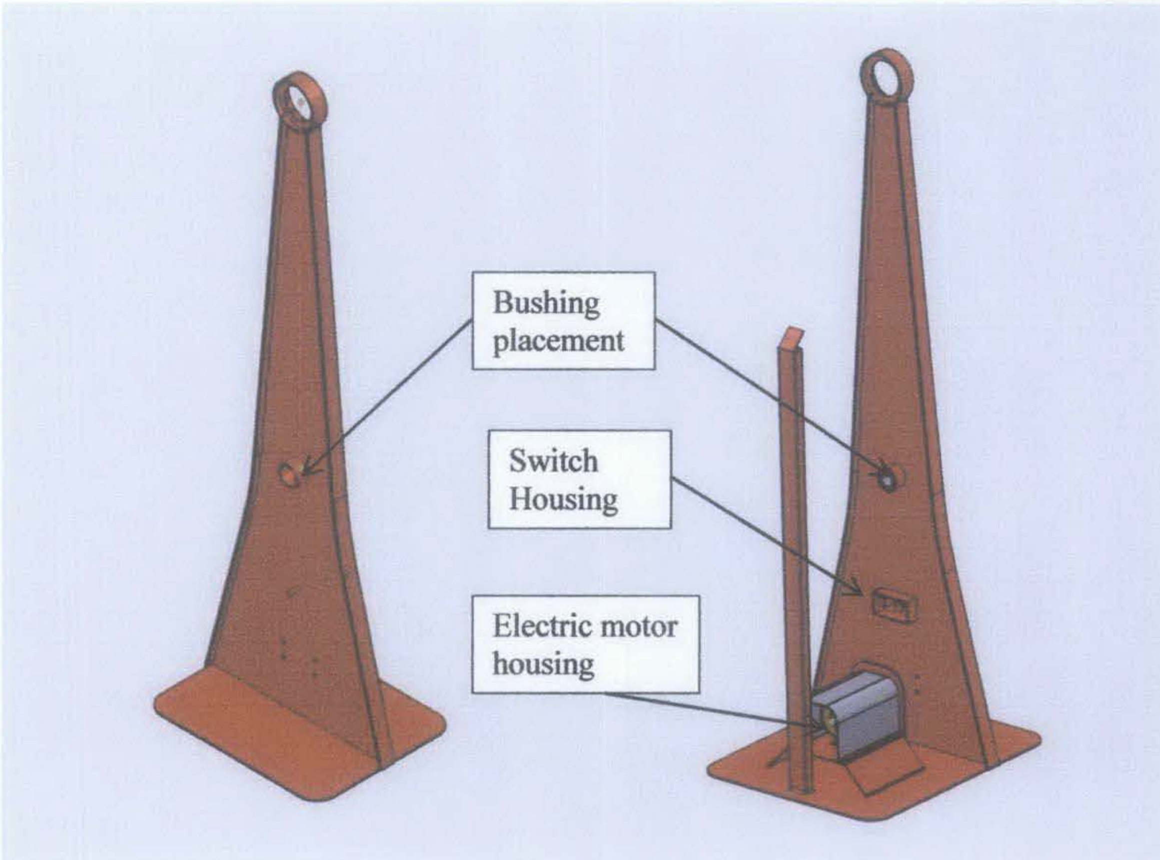


Figure 4.10 Support stand for the PTC

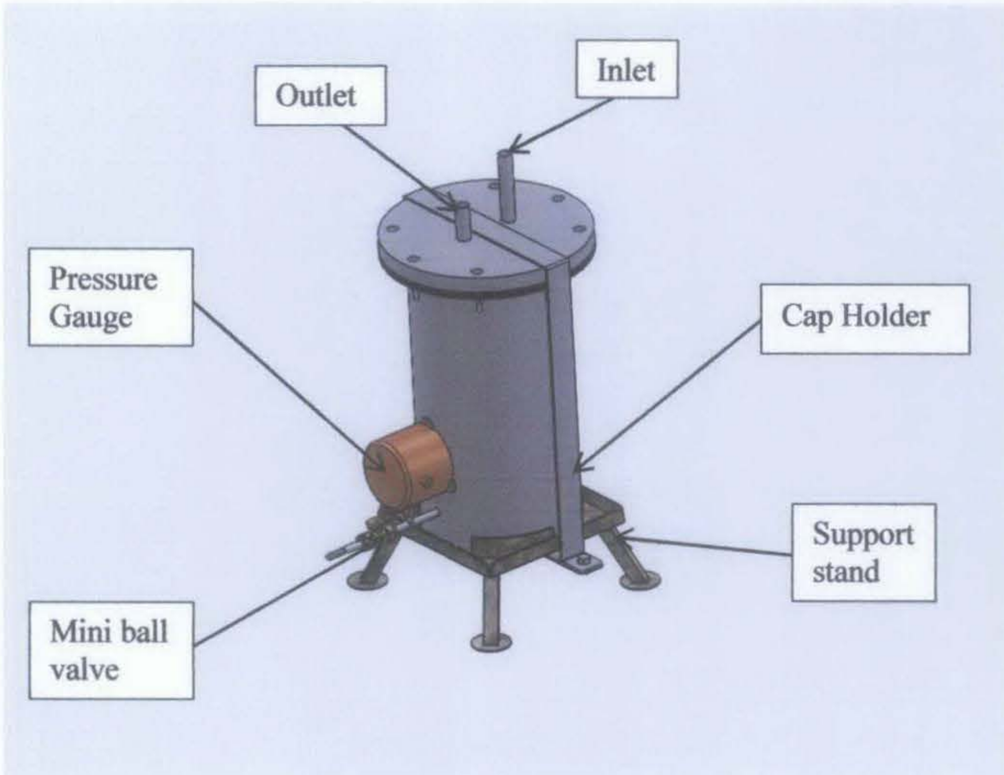


Figure 4.11 Thermal storage tank for water and therminol-72

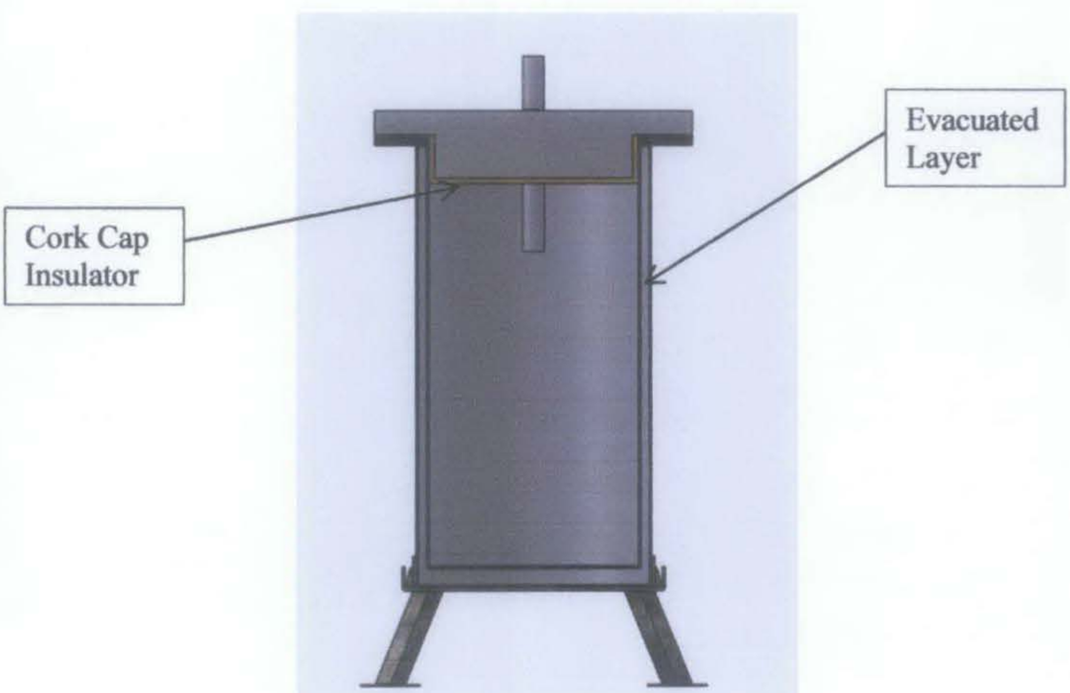


Figure 4.12 Sectioning of the thermal storage tank

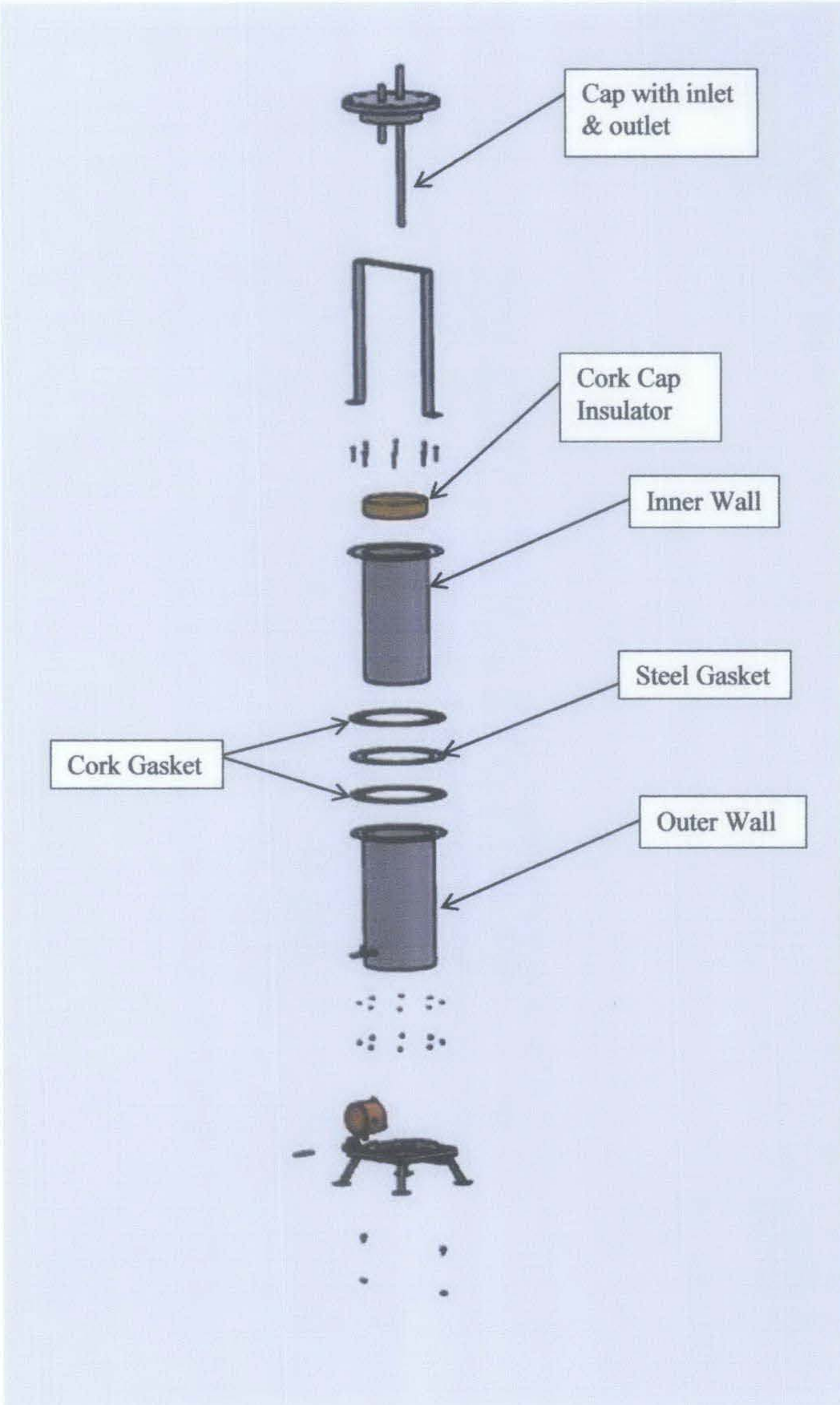


Figure 4.13 Break-up of the thermal storage tank

Some auxiliary component also has been designed to helps the completion of the system which will be shown in the Figure 4.14 and Figure 4.15 below. Noted that some of these auxiliary components are already on the market and will be just integrated into the system since the specification is acceptable the specification the heat exchanger can be viewed in the Appendix 7.

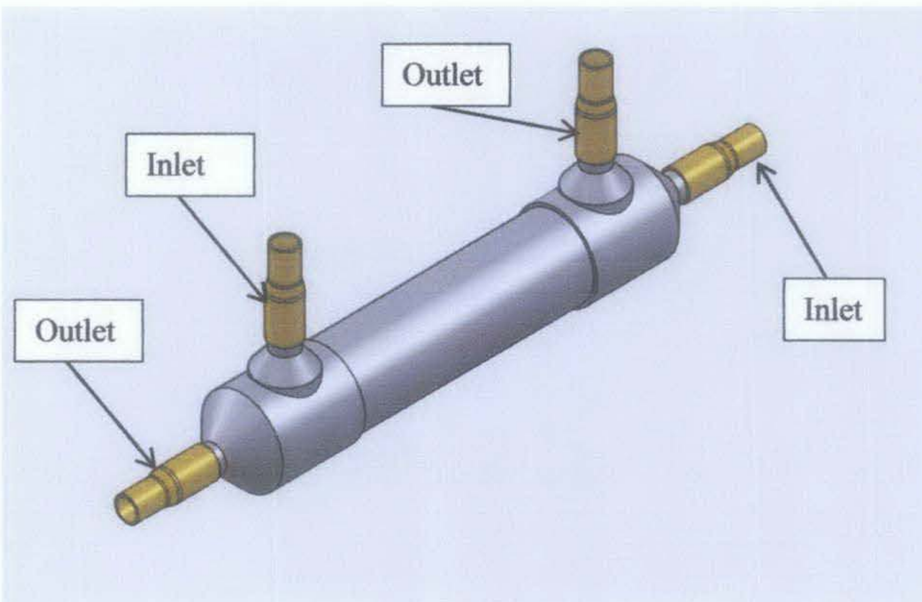


Figure 4.14 Shell and tube heat exchanger with the 1inch- 20 mm tube reducer

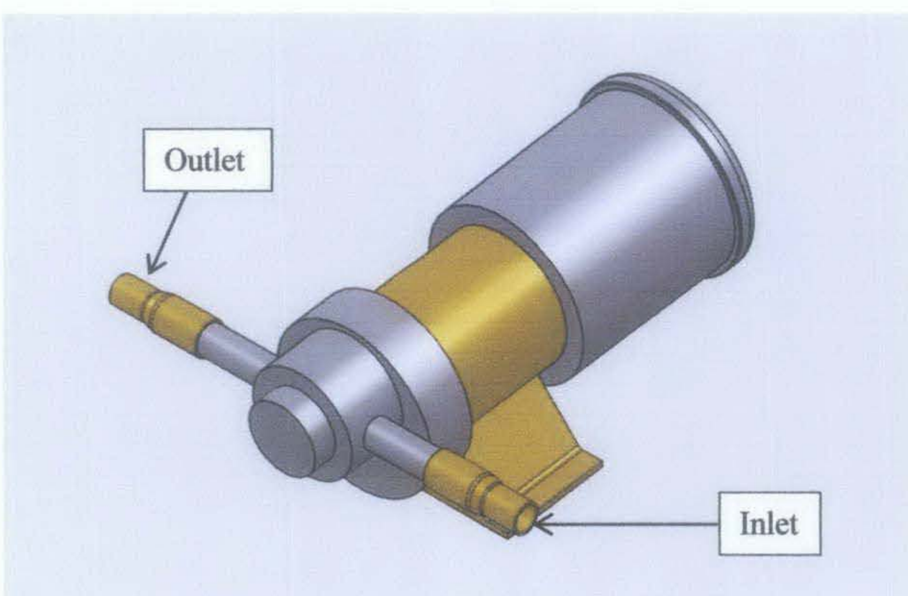


Figure 4.15 High temperature pump with the 1inch- 20 mm tube reducer

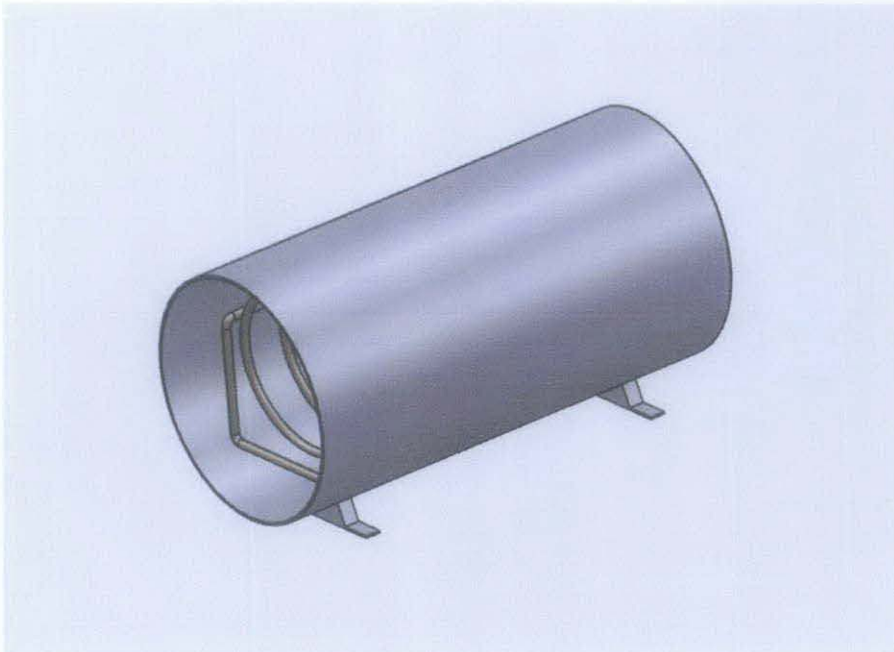


Figure 4.16 Dummy load

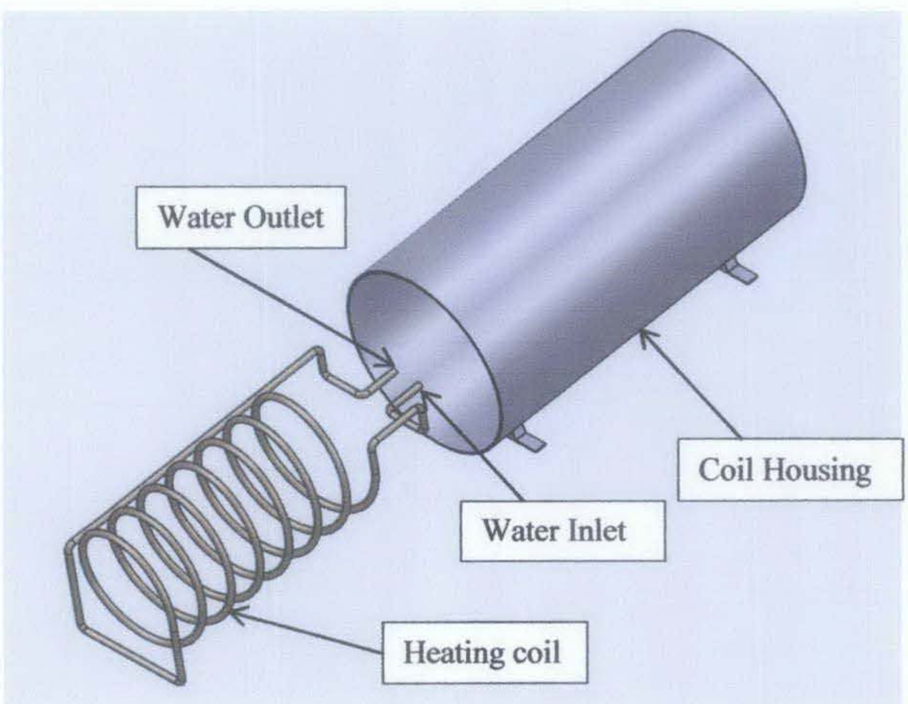


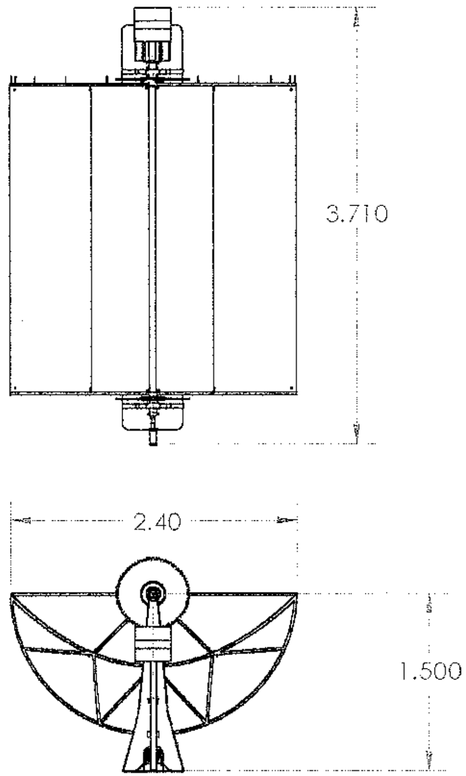
Figure 4.17 Dummy load break-up

Figure 4.18 High temperature flow meter

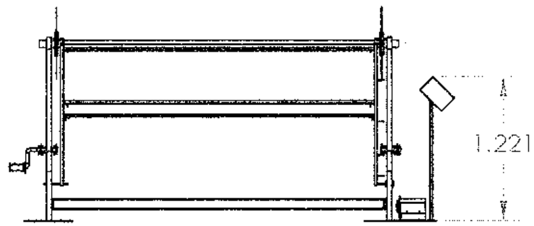
Figure 4.19 10 mm inlet outlet ball valve

Basically the high temperature pump (Figure 4.15) will pump the Therminol-72 from the storage tank (Figure 4.11) to the PTC (Figure 4.5 to 4.6) and will go to through the heat exchanger (Figure 4.14) before being stored back in the storage tank (Figure 4.13). At the same time, the water will be pumped from the water storage tank the same as Figure 4.11 but will be containing the water through the heat exchanger to be heated by the Therminol-72 and will go through the dummy load (Figure 4.17) to measure the final temperature of the load. After that the heated water will be going through the condenser (Figure 4.14) to reduce its temperature and stored in the storage tank. Noted that the condenser is the same heat exchanger but will be used for cooling the hot water. The running water will be used as coolant running through the condenser. The whole layout of the system can be viewed in the Appendix 5. The flow rate of both liquid is regulated by ball valve (Figure 4.19) and measured with the high temperature flow meter.

Figure 4.18 and 4.19 shows the technical drawings of the assembled products and the main components of the system. Currently, the type of the fasteners that will be used for the system is the nut and bolt connection. The fasteners list can be viewed along the other parts in the bill of material in the assemblies.



ITEM NO.	PART NUMBER	QTY.
1	Saddle PTC - MANUAL OP	1
2	PTC Complete Assembly	1
3	[saddle] rotary linear bushing	1
4	small sprocket 9 teeth for ANSI 40 chain (manual control) (drive side)	2
5	small sprocket 9 teeth for ANSI 40 chain (manual control)	2
6	Handle grip	1
7	[PTC] Split Pin	6
8	[PTC] Lock Stick	1
9	[PTC] Handle bar v2	1
10	PTC Saddle Auto Side	1
11	[PTC] stick connector bar	1
12	[PTC] Auto Shaft	1
13	small sprocket 9 teeth for ANSI 40 chain	1
14	[Electrical Cabinet] Small RHC Series NEMA 3R Hinge-Cover	1
15	Pusher Stick	11
16	[Bolts & Nuts] M10 x 40 Bolt	8
17	[Bolts & Nuts] M10 x 10 Nut	9
18	[Bolts & Nuts] M6 x 1.6 Flat Washer	3
19	[Bolts & Nuts] M6 x 8 Nut	3
20	[PTC Saddle] Switch Housing Cover	1
21	[Screw] M2 x 12 Screw	2
22	[Bolts & Nuts] M4 x 20 Bolt	4
23	[Bolts & Nuts] M4 x 5 Nut	4
24	[Bolts & Nuts] M3 x 10 Bolt	2
25	[Bolt & Nut] M8 x 20 Screw	12
26	[Bolts & Nuts] M8 x 5 Nut	12
27	43 -links ANSI No.40 Chain	2
28	72-links ANSI No.40 Chain	2



UNLESS OTHERWISE SPECIFIED: NAME DATE

DIMENSIONS ARE IN METRES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL

FINISH

DO NOT SCALE DRAWING

DRAWN SSJ
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

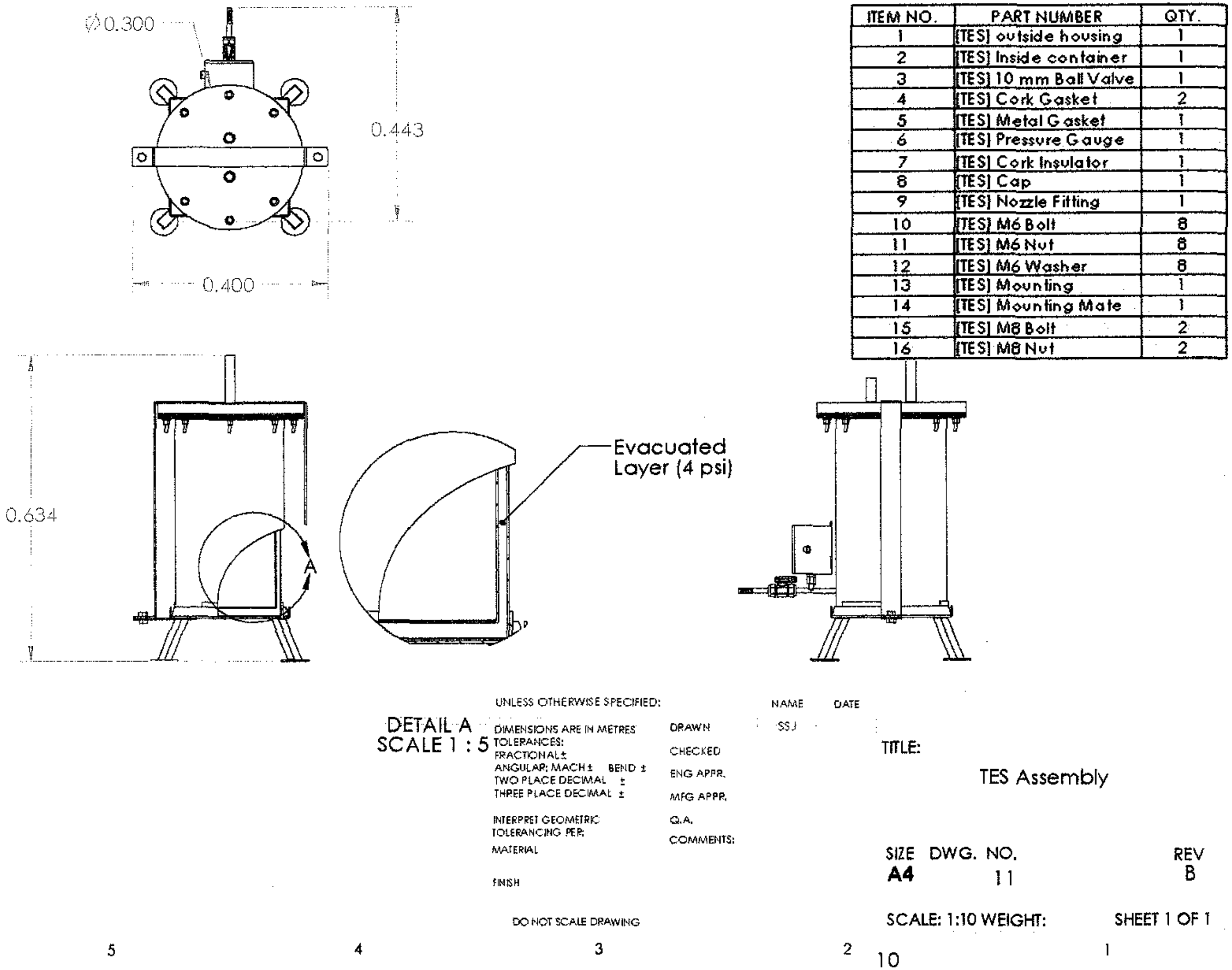
TITLE:
PTC Assembly

SIZE A4 DWG. NO. A-1 REV B

SCALE: 1:50 WEIGHT: SHEET 1 OF 1

5 4 3 2 10 1

Figure 4.20 Bill of materials with the assembly drawing of PTC



ITEM NO.	PART NUMBER	QTY.
1	[TES] outside housing	1
2	[TES] Inside container	1
3	[TES] 10 mm Ball Valve	1
4	[TES] Cork Gasket	2
5	[TES] Metal Gasket	1
6	[TES] Pressure Gauge	1
7	[TES] Cork Insulator	1
8	[TES] Cap	1
9	[TES] Nozzle Fitting	1
10	[TES] M6 Bolt	8
11	[TES] M6 Nut	8
12	[TES] M6 Washer	8
13	[TES] Mounting	1
14	[TES] Mounting Mate	1
15	[TES] M8 Bolt	2
16	[TES] M8 Nut	2

Figure 4.21 Bill of materials with the assembly drawing of TES

4.10 The Assumed Irradiation Arrived at the Receiver Steel Tube

Based on the specification of the evacuated receiver tube and on paper findings the irradiation loss is calculated roughly as the input for the simulation that will be run on the Solidworks 2010. The result is not comparable since actual testing has not been done. The irradiation transferred is summarized in the table 4.9

Table 4.9: Irradiation percentage of transfer and its end value at receiver tube

No.	Description	Percentage Transferred	Total Irradition (W)	Irradiation Transferred (W)
1	From reflective surface to evacuated glass	70 %	3918	2743
2	From the evacuated glass to the steel reciver tube	96 %	2743	2633

From the table it is concluded the irradiation arrived at the receiver steel tube is 2633 W which means only 67.2 percent managed to be transferred. The percentage values are obtained from the specification sheet of the existing material.

4.11 Solidworks Simulation

To see whether safe operation of the vessel, stress and heat analysis is conduct through the use of Solidworks simulation software. The simulations were conducted on two major components of the design that has been identified as the most crucial in the process which is the a part of the PTC, which are the main body and the also the storage tank since this two component are designed from scratch. Not much stressed analysis is done since that is not the focus. The structure integrity also is not a concern since the reflective surface is quite light is guaranteed to be supported by a stainless steel structure.

In a heat transfer, there are three type of transfers which are through conduction, convection, and radiation. The source of the heat in the process is from radiation from the sun which is this project trying to utilize and maximize it whether it can supply acceptable heat to the whole process.

4.11.1 Reflective Surface

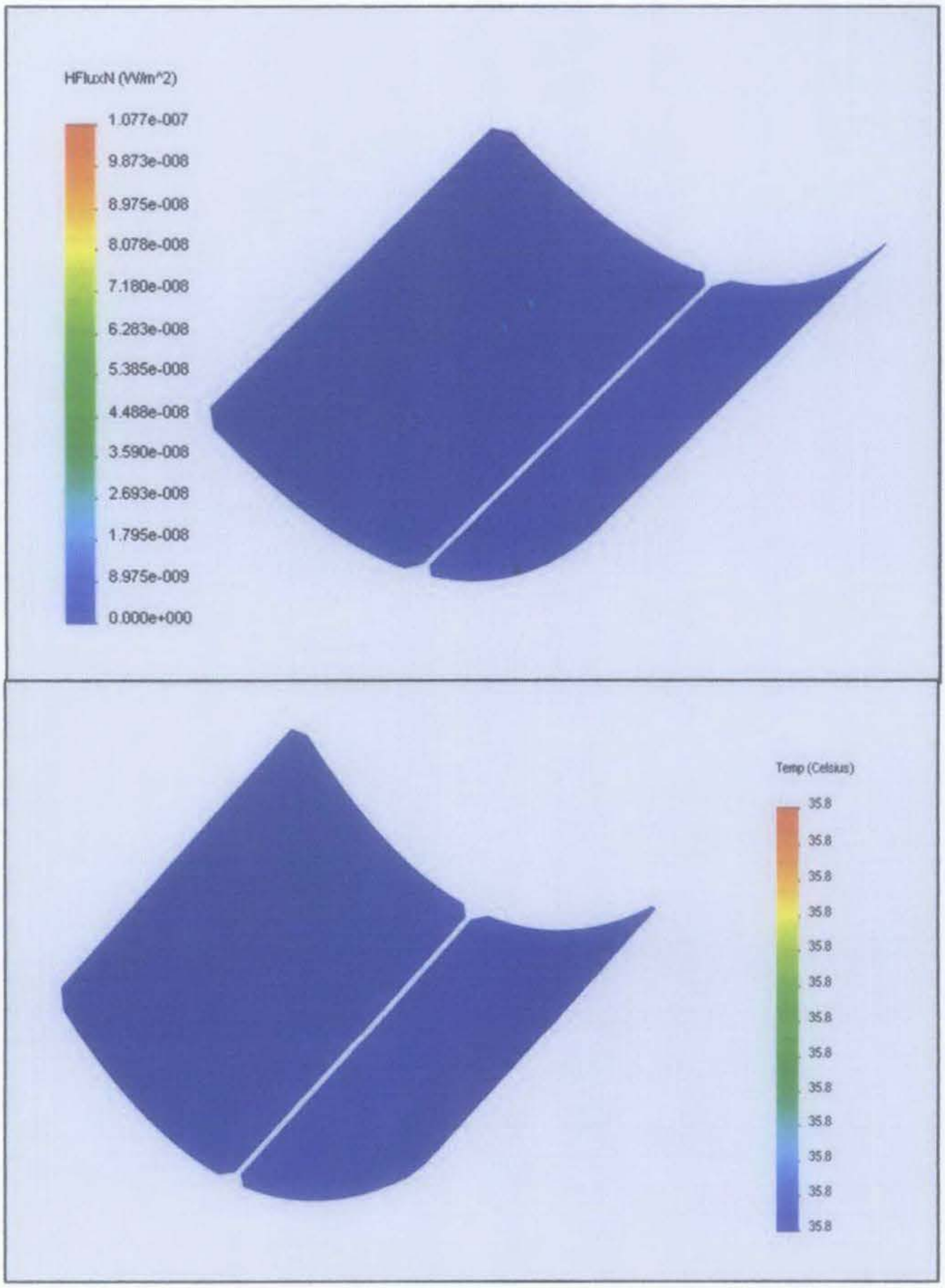


Figure 4.22 Result of thermal simulation analysis on the reflective surface in form of heat flux (top) and temperature distribution (bottom)

For thermal analysis of the reflective surface, Figure 4.22 shown that the elements undergo maximum heat flux 1.077×10^{-7} W/m $^{2.}$ Which is quite low and caused by high reflective index of the coating. The temperature distribution also uniform because the irradiation I assumed to be dispersed evenly across the reflective surface. It cannot be denied that some of the heat is absorbed to the metal surface although it is coated with some coating and causing temperature rise to 35.8 °C across the surface.

4.11.2 Steel Receiver Tube

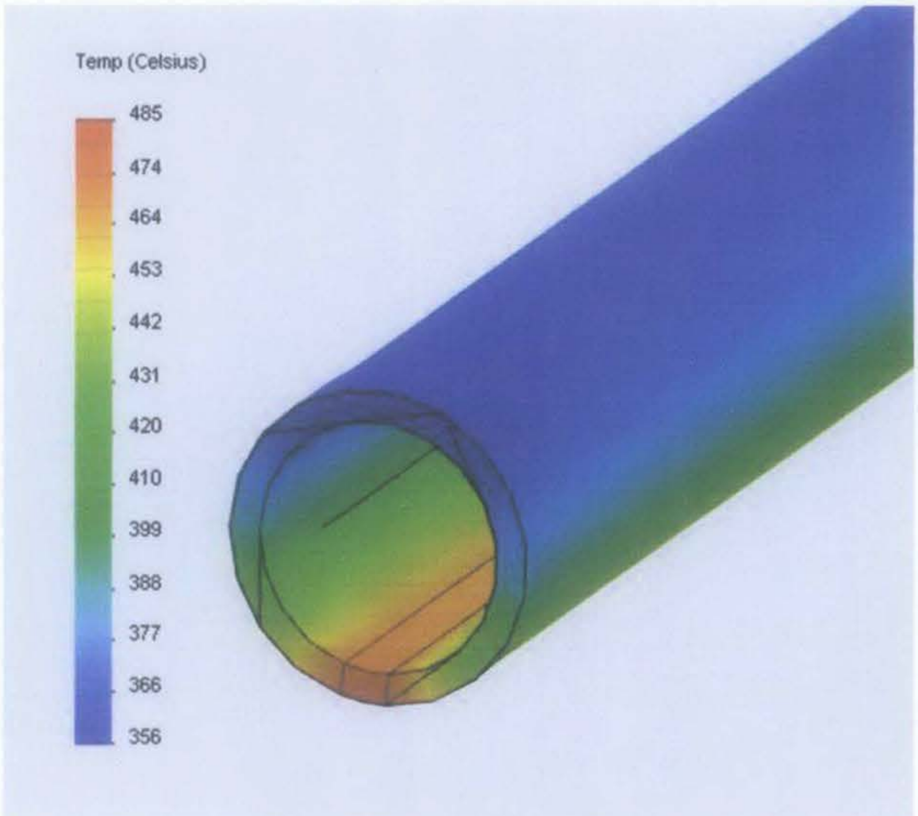


Figure 4.23 Result of thermal simulation analysis on the steel receiver tube

For thermal analysis, Figure 4.23 shown that the elements undergo maximum temperature of 485°C at the bottom of the receiver tube. Heat is not distributed evenly to the entire body with the exception to the body where there is a high concentration of heat at the bottom compared to other areas. This is because the irradiation with the value of 2633 W. Although the concentrated temperature is quite high the tube has not experience any thermal deformation due to high temperature which means the material for the receiver tube is suitable.

4.11.3 Thermal Energy Storage Tank (Therminol-72)

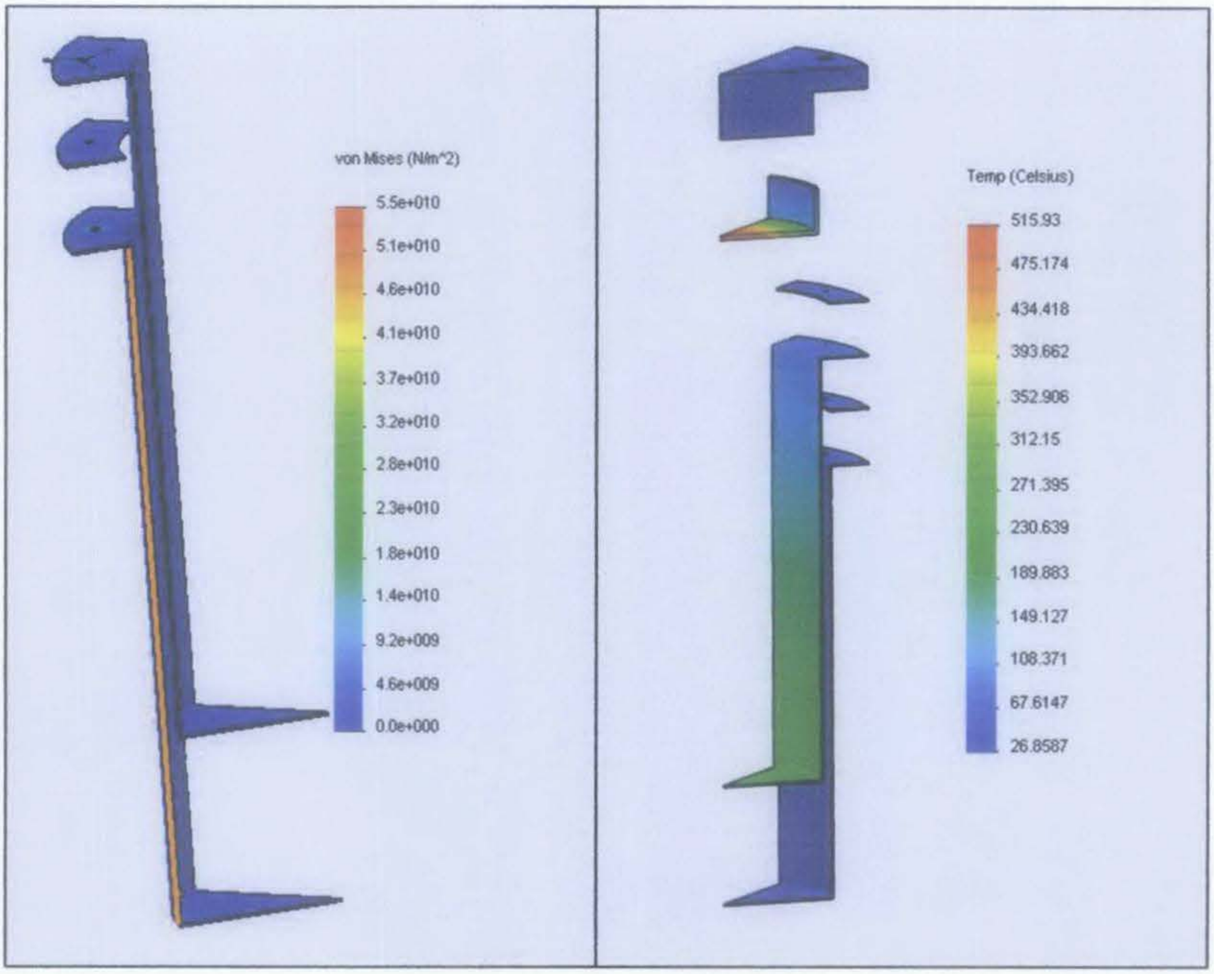


Figure 4.24 Result of stress simulation analysis due to evacuated wall (right) and the temperature of storage tank (left)

Figure 4.24 shown that the elements undergo maximum stressed of 55 MPa due to the existence of the evacuated layer of 4 psi (Please refer pump specification on the Appendix. However the tank has not experienced any mechanical deformation which means the thickness and the pressure of the evacuated layer is acceptable. For the thermal analysis, the maximum temperature undergone by the storage tank is 516 °C concentrated on the cork cap insulator. The high temperature at the cork is due to low specific heat of the cork. The temperature at the outside of the tank is quite low due evacuated layer. This is because the air inside the space between the layers is assumed to be fully removed. But there is still thermal loss on the outside of the tank due to conduction between the inside housing and outside casing although it is insulated by a cork gasket.

4.12 Therminol-72 Flow Rate Determination

Table 4.10 shows the flow rate considering there are full heat transfer between the Therminol -72 and the steel receiver tube. The calculation given is based on the specification of the component itself and the result carried out from the Solidworks simulation for the temperature distribution in the Figure 4.21.

Table 4.10 Summary of input and output values for heat transfer between Therminol-72 and steel receiver tube

INPUT		OUTPUT	
Pipe ID (m)	0.016	Mass Flow Rate (kg/s)	0.003195
Pipe Cross Section Area (m^2)	0.000201062	Fluid Velocity (m/s)	2.1102E-02
Therminol-72 Density (kg/m^3)	753	Volumetric Flow Rate (m^3/min)	2.55E-04
Therminol-72 Viscocity (m^2/s)	2.20E-07	Volumetric Flow Rate (l/min)	0.255
Heat Supplied, Q	2633	Capacity of the PTC (l/day)	183.3
Specific Heat kJ/kg.K	2528	How many HTF rotation for reheating	15
Inside temperature(°C)	356	Capacity of the tank (m^3)	0.0125
Outside Temperature (°C)	30	Capacity of the tank (l)	12.5
Temperature Difference (°C)	326	Reynold Number	1535
Volumetric Flow Rate (m^3/s)	4.24288E-06	Moody Friction Factor	0.0563
Hours of operation per day	12	Pressure Drop (kPa/100m)	0.032796

Based on Table 4.10 it is concluded that for a fully transferred heat, the volumetric flow rate of the Therminol-72 is at 0.255 liter/min. However, the minimum Reynolds Number of this flow rate in the tube is 1535 which is less than 2000. The flow is considered laminar. Since the flow is laminar, the heat transfer relies entirely on the thermal conductivity of the fluid to transfer heat from inside a stream to the pipe or heat exchanger wall.

4.13 Water Flow Rate Determination in Heat Exchanger

Table 4.10 shows the flow rate of the water needed for the heat exchanger considering there is full heat transfer between the based on the specification of the heat exchanger. The end result for the water flow rate is achieved using NTU method combined with trial and error method and the result is summarized in Table 4.11.

Table 4.11 Summary of input and output values for heat transfer water in the heat exchanger

INPUT	
U overall (W/m^2.C)	541
C min kJ/kg.K (Therminol-72)	2528
C max kJ/kg.K (Water)	4217
Surface Area (m^2)	1.25
Inlet water temperature(°C)	27
Outlet water temperature (°C)	100
Temperature Difference (°C)	73
OUTPUT	
Mass Flow Rate (kg/s)	0.006574
Effectiveness, ε	0.88

4.14 Auxiliary Item

In order to perform its duties adequately, the system will be equipped with few auxiliary items; thermocouple, 24V DC electric motor, motor controller circuit, vacuum pump. The allocations for the equipment are integrated into the design but some modifications are still necessary to ensure the integrity and safety of the system. Selection of the items is based on a mix and match to the design and needs of the system. Table 4.6 shows proposed types of the auxiliary items and it details

Table 4.12 The proposed auxiliary components used with the system

Parts of Components	**Functions**	**Type**	**Material**	**Specifications**
Thermocouple	To take temperature measurement in the system	Type K probes	Stainless Steel	Temperature Range: (-50 C to 500 C)
Electric Motor	To automatically handle the solar tracking	DC Bidirectional Motor	-	Bosch GPA 24 V 750 W
Motor Controller Circuit	To control the movement of solar concentrator	-	-	12 V powered circuit refer Figure 4.23
Vacuum Pump	To maintain the vacuum space within the storage tank wall	-	-	4 psi vacuum pressure max

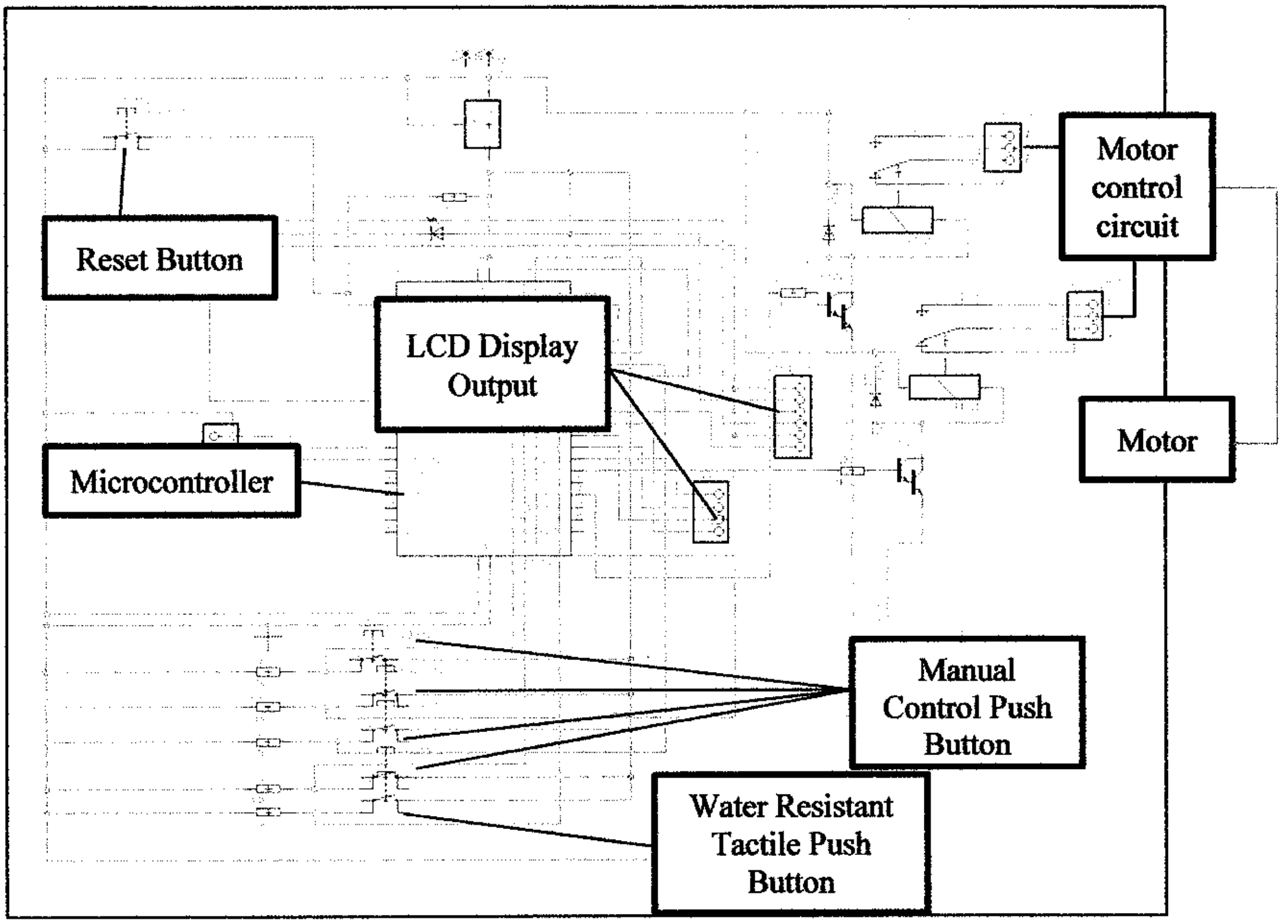


Figure 4.23 Schematic circuit for the automatic solar tracking implementation

Based on Figure 4.23, the circuit will function to control the solar tracking function during its operation. The circuit will be programmed to rotate the parabolic trough

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the research that had been done so far, the suitable concentrator shape is the parabolic trough as it has the largest receiving surface for the same area coverage. In term of material, stainless steel is the most suitable material by far to handle the high temperature operation. The irradiation measurement shows that the average irradiation of UTP is down by half with the value of total radiation of 555 W/m^2 compared to most countries that apply the solar concentrating technology. This will lead to a double size concentrator compared the usual used to supply the same power. For the HTF selection, the Therminol-72 will be used and the piping dimension and selection also has been completed. Some technical drawing of system have completed (refer Appendix 6). Simulation using Solidworks had also been done and even though the result is favorable, some design modifications will improve it survivability and reduce material fatigue will be considered. Solidworks thermal test result also had shown that the accumulation of heat at the bottom receiver tube which where the reflected irradiation concentrated, however, there are no deformation caused by high temperature and the material is suitable for the purpose.

In term of objective, a design for solar concentrator and the storage tank was produced at the end of this project however refinement of the design in term of allocations and modifications to fit the proposed equipment (Section 4.12) are still need to be done.

5.2 Challenge

Until this point of study there a few problem that been faced. The main problem is to determine the size of the solar concentrator, given the smallest evacuated receiver tube is still massive in size; the concentrator size will be quite big for a miniature scale. This is not favorable in terms of cost and space saving.

5.3 Recommendations

Firstly, the Solidworks simulations are not very accurate in term of testing the products due to the variety of factors involved thus testing of the final product still need to be done in order to fully certified the product reliability. Which means the the product should be fabricated and and fully tested in the real environment. The application of Solidworks is only suitable for preliminary test but not the actual ones. For the storage tank, it is recommended to install an electrical heater to maintain the temperature of the HTF so that the fluid flow can be flowed much faster and have a better thermal performance. An alternative for Therminol-72 also need to be find as it is quite costly compared to water.

REFERENCES

aip.org (1977). *Fundamental of Heat Exchanger* [Online]. Available: http://www.aip.org/tip/INPHFA/vol-2/iss-4/p18.pdf. (Accessed on December 15th 2011)

Çengel, Y. A. (2003) *Heat Transfer: A Practical Approach 2nd Edition*, McGraw Hill, Boston.

Cengel, Y.A. and Boles, M.A. (2007) *Thermodynamics An Engineering Approach Sixth Edition (SI Units)*, McGraw Hill, USA.

Darling, D. (2011) .*Dewar Tube* [Online].
Available:http://www.daviddarling.com
(Accessed on June 15th 2011)

Duffie, J.A, Beckman, W.A. (1991) *Solar Engineering of Thermal Processes*, Second Edition, John Wiley & Sons, Inc., USA.

Free Patents Online (1991). *Solar Grill* [Online]. Available: http://www.freepatentsonline.com/5924415.pdf. (Accessed on June 15th 2011)

Free Patents Online (1977). *Solar Heating* [Online]. Available: http://www.freepatentsonline.com/5924415.pdf. (Accessed on June 15th 2011)

Goswami, D.Y., Kreith, F., Kreider, F. (2000) *Priciples of Solar Engineering*, Second Edition, Taylor & Francis Group, LLC., USA.

Ibrahim, N.F., Johani, S.S., Nasir, M.M.N.M, Salleh, M.H, Abadi, A.M, and Wong, L.S (2010), *Micro-controlled Plant House,* Engineering Team Project, Universiti Teknologi Petronas, Perak, MY. Unpublished report

Kleis, S.J. and Bingham, C.E (2001). *Solar Engineering 2001,* ASME, USA.

Kohl, M., Carlsson, B., Jorgensen, G.J., and Czanderna, A.W. (2004) *Performance and Durability Assesment, Optical Material for Solar Thermal System,* ELSEVIER, Ltd., UK.

Majdi, K.N.A (2011), *Performance Improvement of Photovoltaic Panels Through Mitigation of Surface Temperature Cooling and Debris Removal,* Final Year Project Dissertation, Department of Mechanical Engineering, Universiti Teknologi Petronas, Perak, Malaysia. Unpublished report

Sani, M.H.H, Johani, S.S., Bahrin, and M.K.K., Alehan, M.N. (2011), *Solar Power Integration in Hydroelectric Dam,* Mechanical Engineering Department, Universiti Teknologi Petronas, Perak, MY. Unpublished report

Shah, A., Darr, J.M., Medic, D., Anex, P.R., Khanal, S., and Maski, D. (2011), *Techno-economic Analysis of a Production-scale Torrefaction System for Cellulosic Biomass Upgrading* [Online].
Available:http://onlinelibrary.wiley.com/doi/10.1002/bbb.336/full.
(Accessed on June 15th 2011)

Shuai, Y., Wang, F., Xia, X., and Tan, H. (2010), *Ray-Thermal-Structural Coupled Analysis of Parabolic Trough Solar Collector System,* School of Energy Science and Engineering, Harbin Institute of Technology Engineering Department, CN.

Trink,W., Mawhinney, M.H., Shannon, R.A., Reed, R.J., Garvey, J.R. (2004) *Industrial Furnaces Sixth Edition,* John Wiley & Sons, Inc., USA.

USDA Forest Service (2011) .*Dry Bone* [Online].
Available: http://www.srs.fs.usda.gov/forestops/biomass.htm. *(*Accessed on June 15th 2011*)*

Umea University (2011) .*Torrefaction* [Online].
Available:http://www.tfe.umu.se/english/research/etpc/Research+areas/torrefaction/ *(*Accessed on June 15th 2011*)*

Wikipedia Online Encyclopedia (2011). *Torrefaction* [Online].
Available: http://en.wikipedia.org/wiki/Torrefaction. *(*Accessed on June 15th 2011*)*

Wikipedia Online Encyclopedia (2011).*Solar Tracker* [Online].
Available: http://en.wikipedia.org/wiki/Solar_tracker. *(*Accessed on June 15th 2011*)*

Wikipedia Online Encyclopedia (2011) .*Dewar tube (vacuum flask)* [Online].
Available: http://en.wikipedia.org/wiki/Dewar_tube. *(*Accessed on June 15th 2011*)*

Wikipedia Online Encyclopedia (2011) .*Solar thermal collector* [Online].
Available: http://en.wikipedia.org/wiki/Solar_thermal_collector. *(*Accessed on June 15th 2011*)*

APPENDICES

Appendix 1 : Gantt Chart for Second Semester (Final Year Project 1)

Appendix 2 : Gantt Chart for Third Semester (Final Year Project 2)

Appendix 3 : Irradiation Tabulation for UTP

Appendix 4 : Material Properties

Appendix 5 : Concept Modeling of The System

Appendix 6 : Completed Technical Drawing of Main Component of the System

Appendix 7 : Heat Exchanger Specification

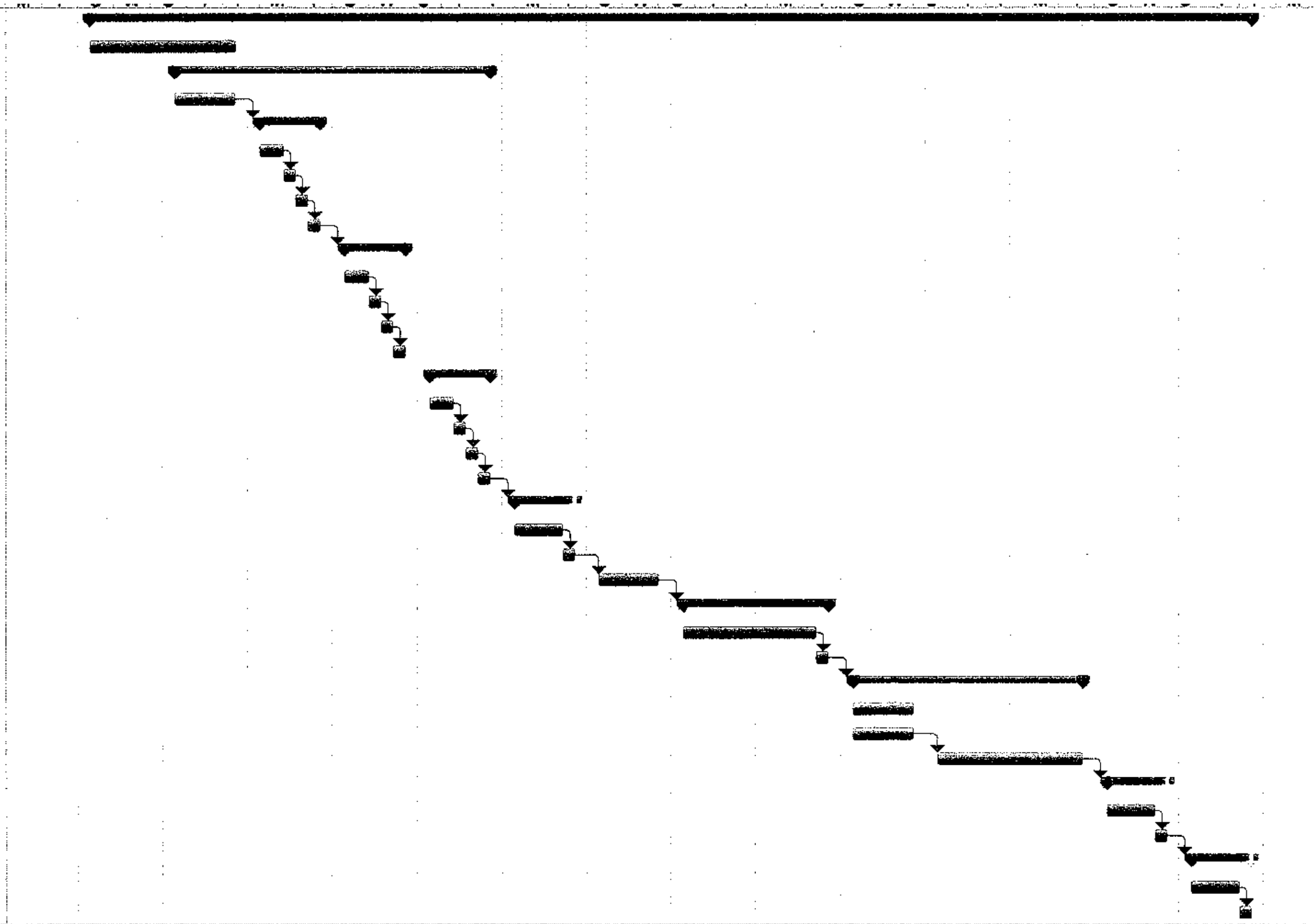
Appendix 8: High Temperature Pump Specification

Appendix 9: DC motor Specification

Appendix 10: Motor Controller Coding Sample

APPENDIX I

ID	Task Name	Duration
1	**FINAL YEAR PROJECT 1**	**70 days**
2	**Selection of topic**	2 wks
3	**Preliminary research works**	**20 days**
4	Research about scope of study	1 wk
5	**Research about the design requirement**	**5 days**
6	Thermal concentrator	2 days
7	High Pressure Heating Vessel	1 day
8	Heat Pipe	1 day
9	Thermal Storage Tank	1 day
10	**Research about material to be used**	**5 days**
11	Thermal concentrator	2 days
12	Heat Exchanger	1 day
13	Piping & Pump	1 day
14	Thermal Storage Tank	1 day
15	**Research on solar tracker**	**5 days**
16	Circuit & Coding	2 days
17	Stepper Motor	1 day
18	Power Supply	1 day
19	Components	1 day
20	**Extended proposal defence**	**5 days**
21	Devising the proposal draft	4 days
22	Submission	1 day
23	**Research and development of concept model**	1 wk
24	**Proposal defence**	**10 days**
25	Devising the proposal draft	9 days
26	Submission	1 day
27	**Project works continue**	**15 days**
28	Finalize the design requirement	1 wk
29	Finalize the material	1 wk
30	Development of final design and early drawing	2 wks
31	**Interim draft report**	**5 days**
32	Devising the interim draft	4 days
33	Submission	1 day
34	**Interim report**	**5 days**
35	Amendment of the interim draft	4 days
36	Submission	1 day

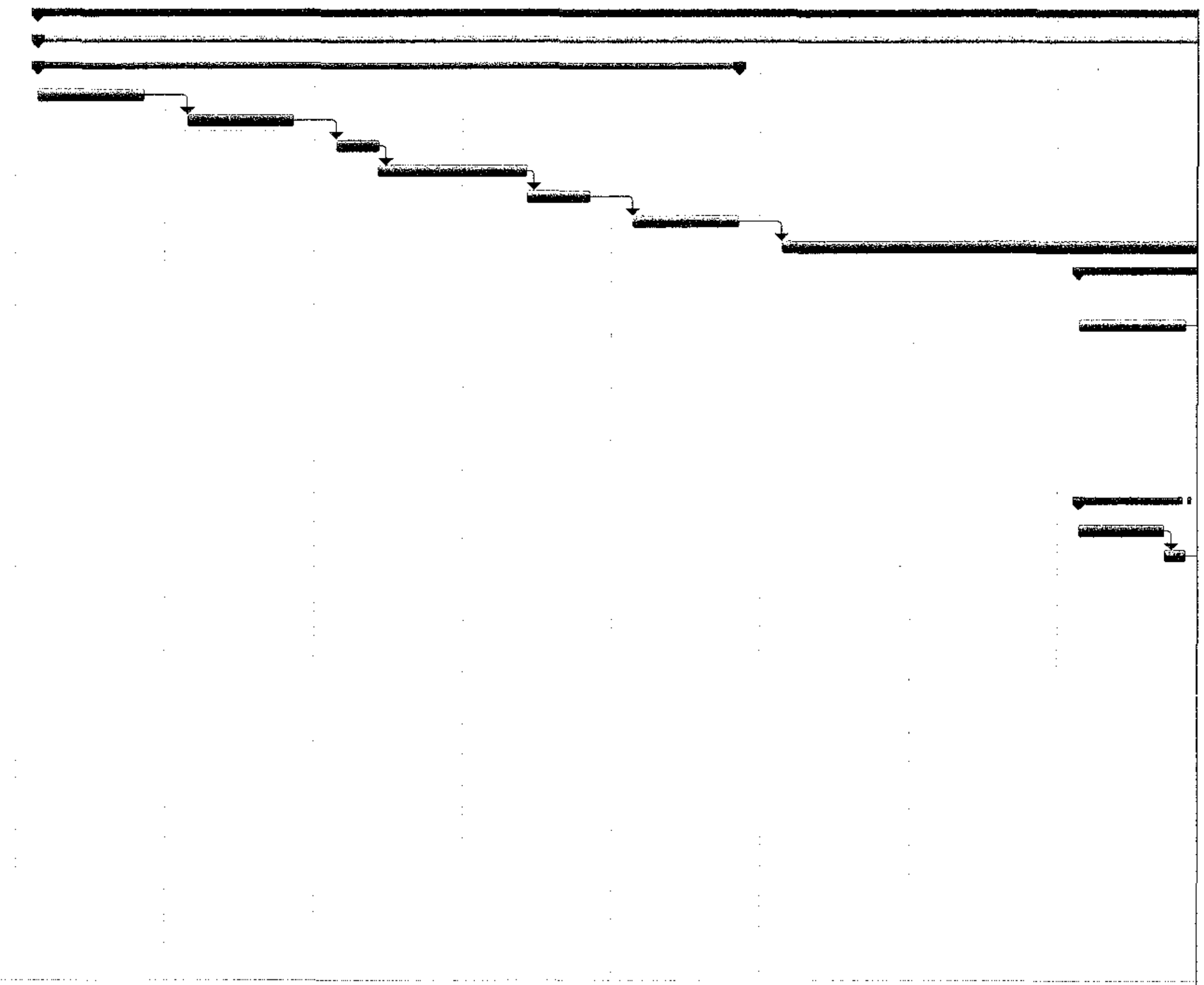


Project: FYP 1 Gant Chart
Date: Wed 1/18/12

Task
Split
Milestone
Summary
Project Summary
External Tasks
External Milestone
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
Progress
Deadline

APPENDIX 2

1	FINAL YEAR PROJECT 2	76 days
2	Continuation of works	61 days
3	Detail design of the system	25 days
4	Thermal concentrator	1 wk
5	Thermal Storage Tank	1 wk
6	Piping and pump	2 days
7	Dummy Load	1 wk
8	Solar tracking system	3 days
9	Assembly of the whole system	1 wk
10	Detail drawing and simulation	6 wks
11	Technical drawing and solidworks simulation testing	23 days
12	Thermal concentrator	1 wk
13	Thermal Storage Tank	1 wk
14	Piping and Pump	2 days
15	Dummy Load	1 wk
16	Solar tracking system	3 wks
17	Assembly of the whole system	3 days
18	Vital components simulation	3 days
19	Progress report	5 days
20	Devising the progress report	4 days
21	Submission	1 day
22	Pre-SEDEX	1 wk
23	Draft report	5 days
24	Devising the report	4 days
25	Submission	1 day
26	Dissertation (Soft bound)	5 days
27	Amendment of report	4 days
28	Submission	1 day
29	Technical Paper	5 days
30	Devising the technical paper	4 days
31	Submission	1 day
32	Oral presentation	5 days
33	Presentation Preparation	4 days
34	Evaluation Session	1 day
35	Dissertation (Hard bound)	5 days
36	Hard bound process	4 days
37	Submission	1 day



Project: FYP 2 Gant Chart
Date: Wed 1/18/12

Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Progress | Deadline

APPENDIX 3

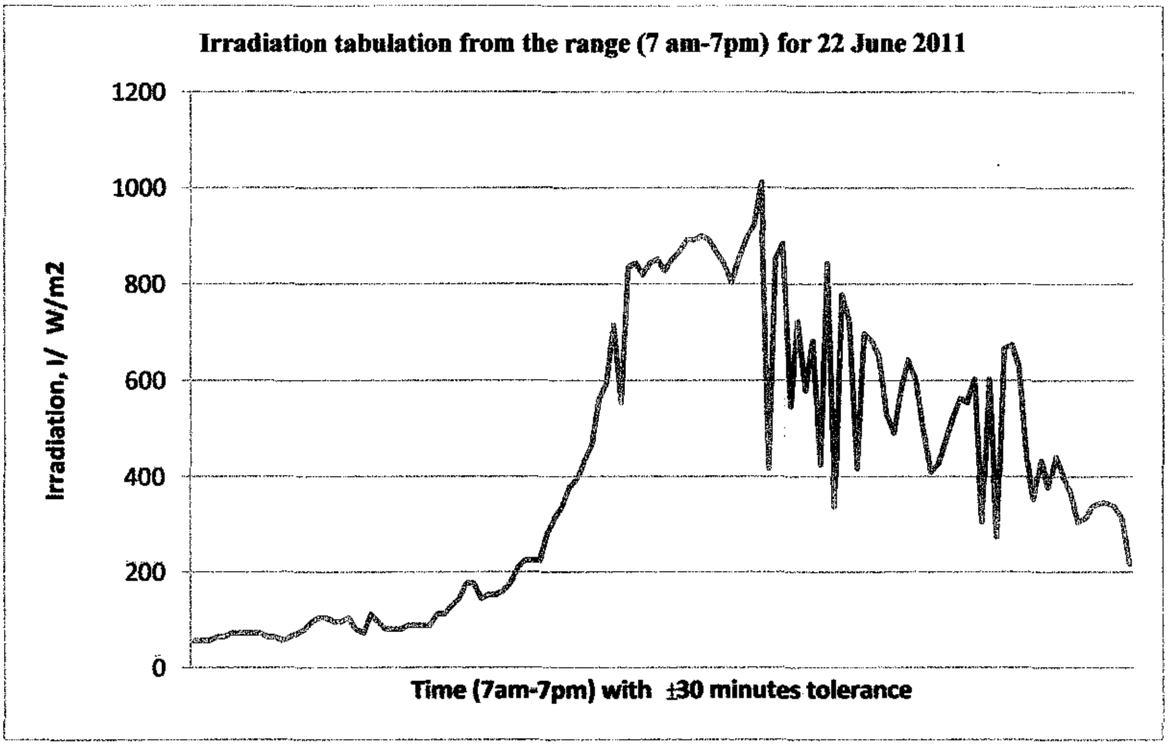


Figure C1.1: Average Irradiation tabulation for UTP for 22 June 2011

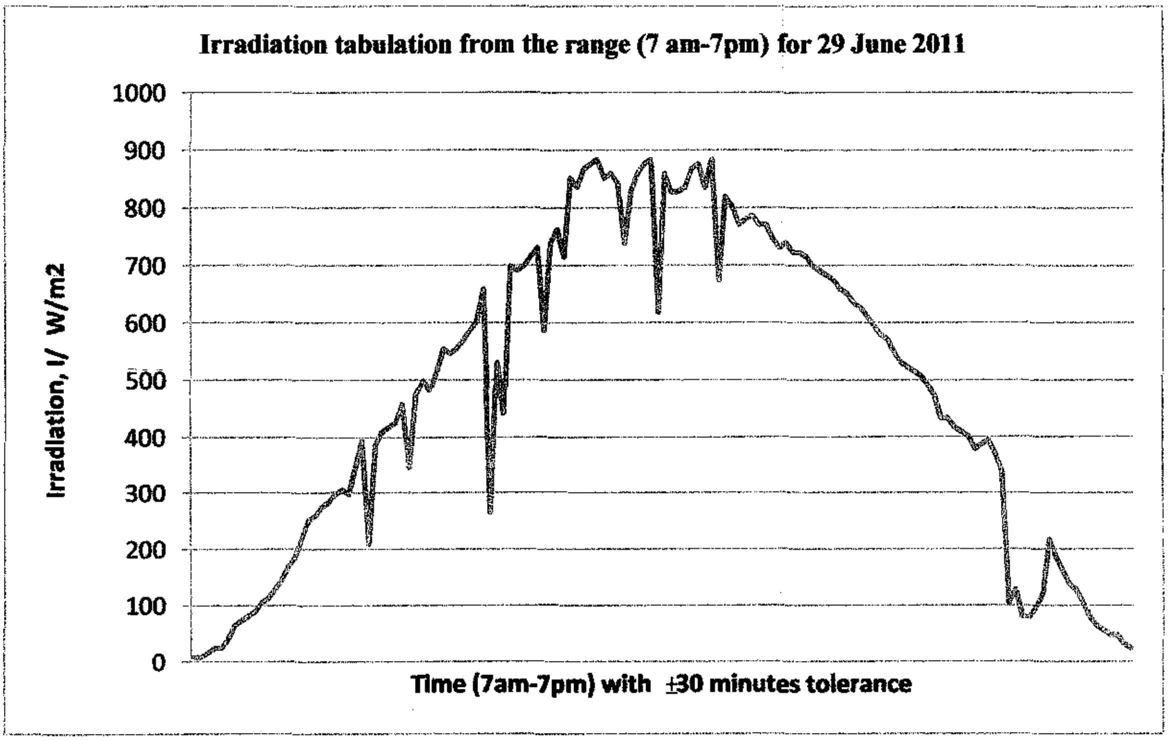


Figure C1.2: Average Irradiation tabulation for UTP for 29 June 2011

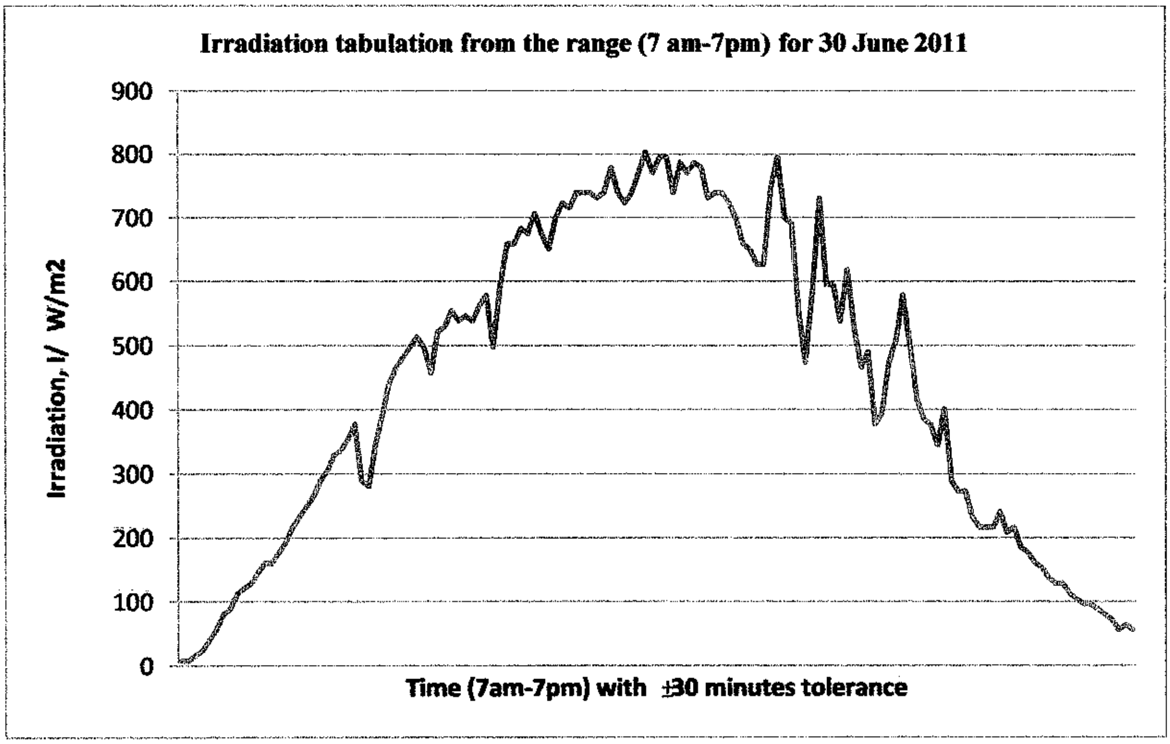


Figure C1.3: Average Irradiation tabulation for UTP for 30 June 2011

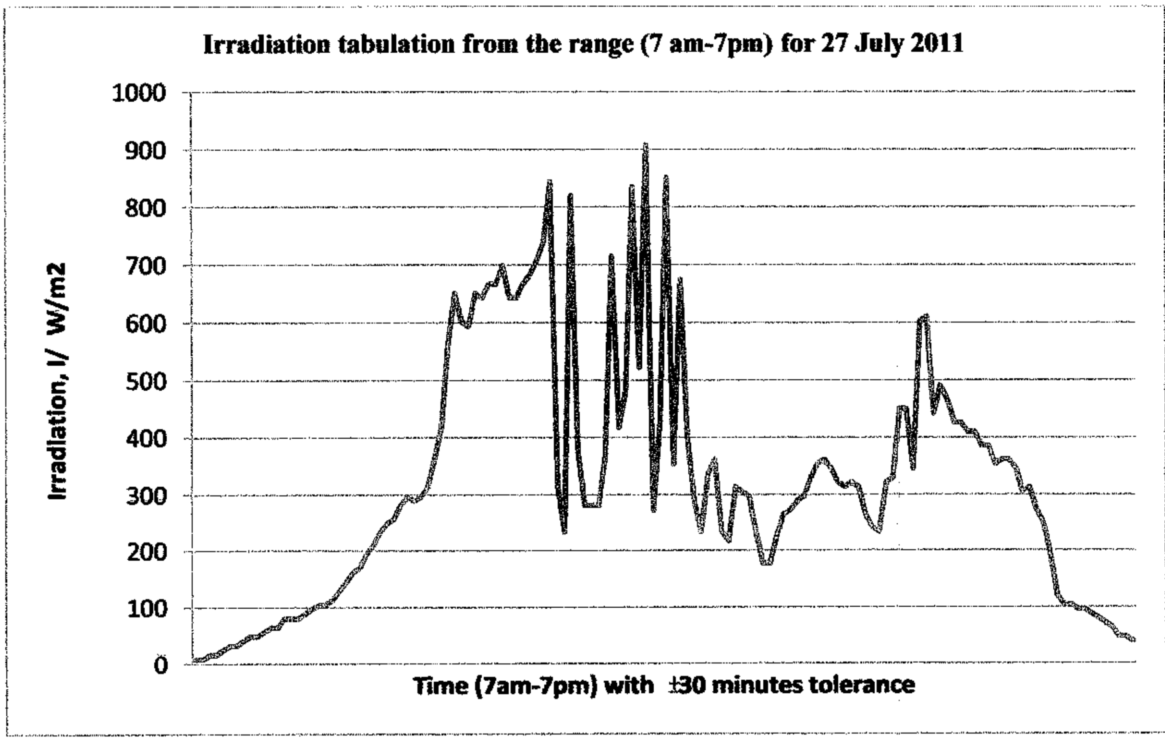


Figure C1.4: Average Irradiation tabulation for UTP for 27 July 2011

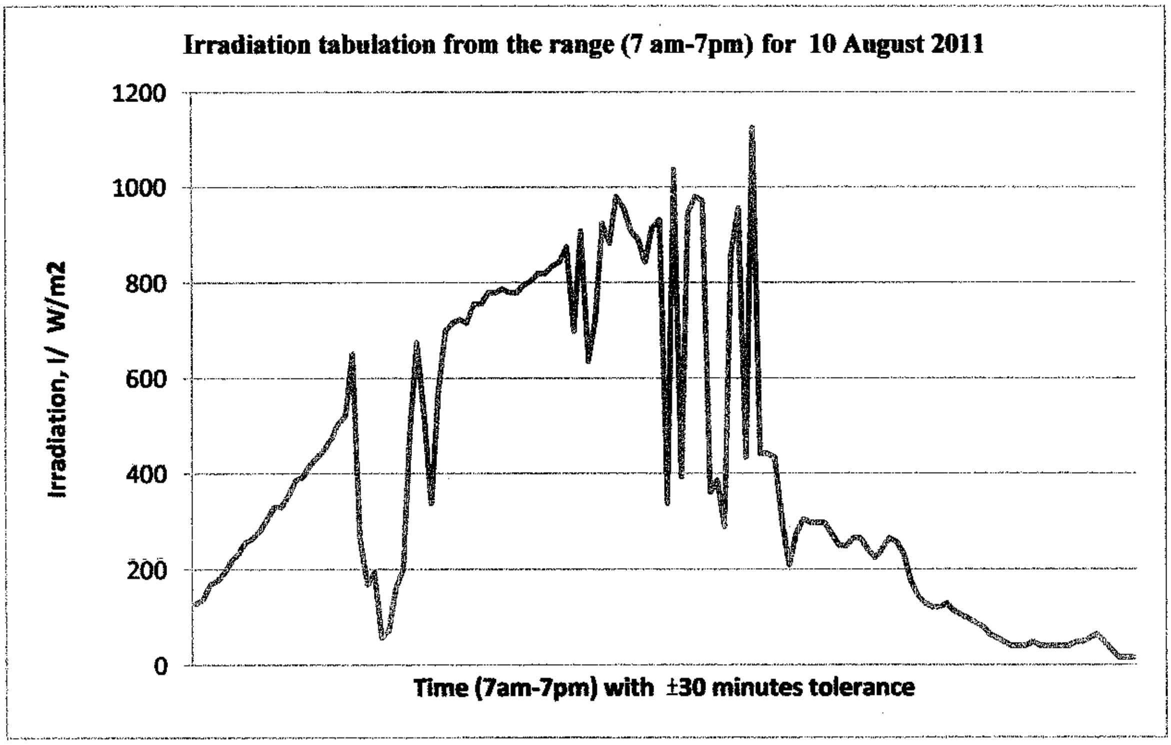


Figure C1.5: Average Irradiation tabulation for UTP for 10 August 2011

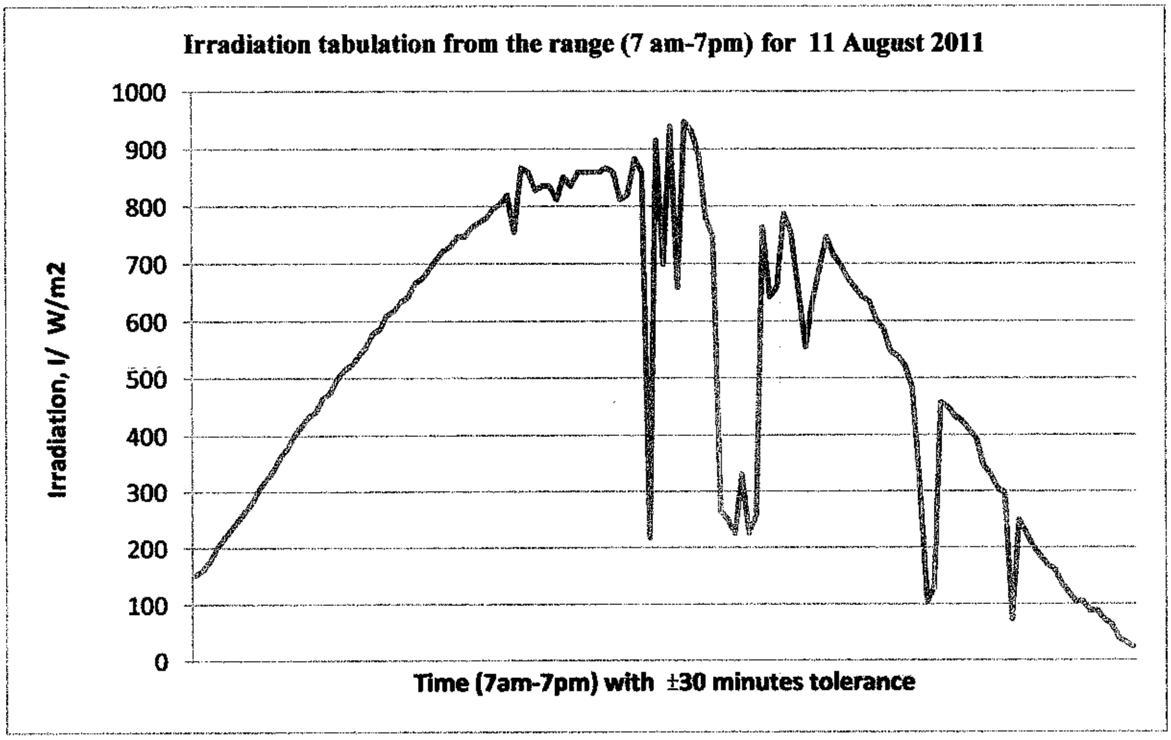


Figure C1.4: Average Irradiation tabulation for UTP for 11 August 2011

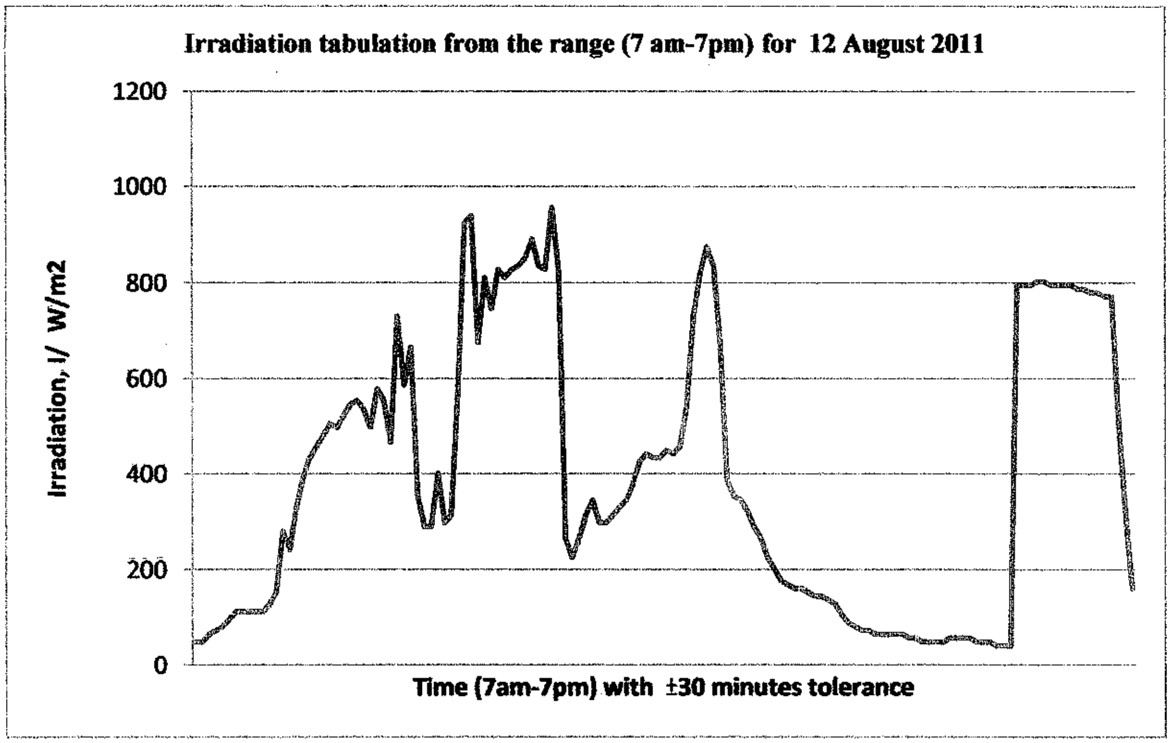


Figure C1.5: Average Irradiation tabulation for UTP for 12 August 2011

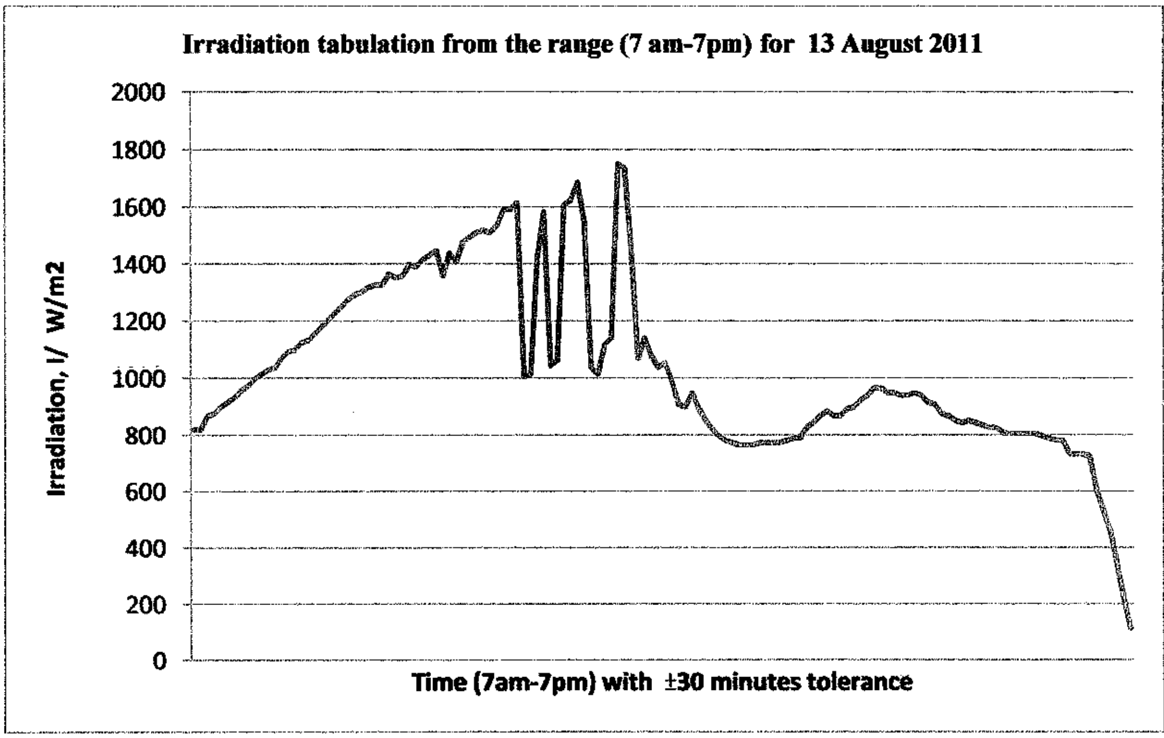


Figure C1.4: Average Irradiation tabulation for UTP for 13 August 2011

APPENDIX 4

Table D1.1: Material properties of candidates for the thermal storage vessel

Materials	Stainless Steel 316 (Anneled Plate)	Low Carbon Steel	Aluminium Alloy
Composition (weight %)	0.04-0.10% C, 2.00% Mn, 1.00% Si, 16.0-18.0% Cr, 10.0-14.0% Ni, 0.045% P, 0.03% S, 2.0-3.0% Mo, and Fe	0.22-0.28% C, 0.60-0.90% Mn, 0.04% P, 0.05% S, and Fe	0.80-0.12% M, 0.40-0.80% Si, 0.15-0.40% Cu, 0.25% Zn, 0.15% Ti, 0.15% Mn,0.04-0.35% Cr, and 95.8-98.6%Al
Tensile Strength (MPa)	515	490	310
Yield Strength (MPa)	205	415	276
Elongation (% in 50mm)	40	15	11
Hardness (Brinell)	217	143	96
Density (kg/m3)	8000	7858	2700
Elastic Modulus (GPa)	193	210	68.9
Mean Co-eff of Thermal Expansion at 0-100°C (μm/m/°C)	15.9	12.1	23.5
Thermal Conductivity at 100°C (W/m.K)	16.3	51.2	17.3
Specific Heat 0-100°C (J/kg.K)	500	486	896

Table D1.2: Material properties of candidates for the HTF

Materials	**Downtherm A**	**Water**	**Therminol-72**
Temperature Range (°C)	12-260	0-100	12-380
Specific Heat ,c_p (J/kg.K)	2200	4190	2528
Vapor pressure @ 400 °C (MPa)	1.064	22	0.573
Density, ρ (kg/m^3)	867	1000	753
Thermal Conductivity (W/m.K) @ 260 °C	0.122	0.607	0.110

Table D2: Therminol -72 properties versus temperature

Properties of Therminol® 72 vs Temperatures

Temperature	Density	Thermal Conductivity	Heat Capacity	Viscosity		Vapour pressure (absolute)
				Dynamic	Kinematic	
°C	kg/m³	W/m.K	kJ/kg.K	mPa.s	mm²/s	kPa
-10	1106	0.143	1.471	383.03	346.32	0.96
0	1097	0.142	1.498	59.23	53.98	1.14
10	1088	0.141	1.525	24.37	22.40	1.35
20	1079	0.140	1.552	13.52	12.53	1.60
30	1070	0.138	1.579	8.69	8.12	1.89
40	1061	0.137	1.606	6.09	5.74	2.24
50	1052	0.136	1.633	4.52	4.30	2.65
60	1043	0.135	1.661	3.50	3.36	3.14
70	1034	0.134	1.688	2.79	2.70	3.71
80	1025	0.132	1.715	2.29	2.23	4.39
90	1016	0.131	1.742	1.91	1.88	5.18
100	1007	0.130	1.769	1.61	1.60	6.12
110	998	0.129	1.796	1.39	1.39	7.23
120	989	0.127	1.823	1.20	1.21	8.54
130	979	0.126	1.850	1.05	1.07	10.08
140	970	0.125	1.877	0.93	0.96	11.89
150	961	0.124	1.905	0.83	0.86	14.03
160	952	0.123	1.932	0.74	0.78	16.54
170	943	0.121	1.959	0.66	0.70	19.50
180	934	0.120	1.986	0.60	0.64	22.98
190	925	0.119	2.013	0.55	0.59	27.07
200	916	0.118	2.040	0.49	0.54	31.86
210	907	0.117	2.067	0.45	0.50	37.54
220	898	0.115	2.094	0.42	0.47	44.18
230	889	0.114	2.121	0.38	0.43	51.98
240	880	0.113	2.148	0.35	0.40	61.14
250	871	0.112	2.176	0.33	0.38	71.88
260	862	0.110	2.203	0.30	0.35	84.49
270	853	0.109	2.230	0.28	0.33	99.29
280	844	0.108	2.257	0.26	0.31	116.63
290	834	0.107	2.284	0.25	0.30	136.96
300	825	0.106	2.311	0.23	0.28	160.79
310	816	0.104	2.338	0.22	0.27	188.70
320	807	0.103	2.365	0.20	0.25	221.38
330	798	0.102	2.392	0.19	0.24	259.65
340	789	0.101	2.419	0.18	0.23	304.44
350	780	0.100	2.446	0.17	0.22	356.85
360	771	0.098	2.474	0.16	0.21	418.15
370	762	0.097	2.501	0.15	0.20	489.83
380	753	0.096	2.528	0.14	0.19	573.63

Note: [illegible]

APPENDIX 5

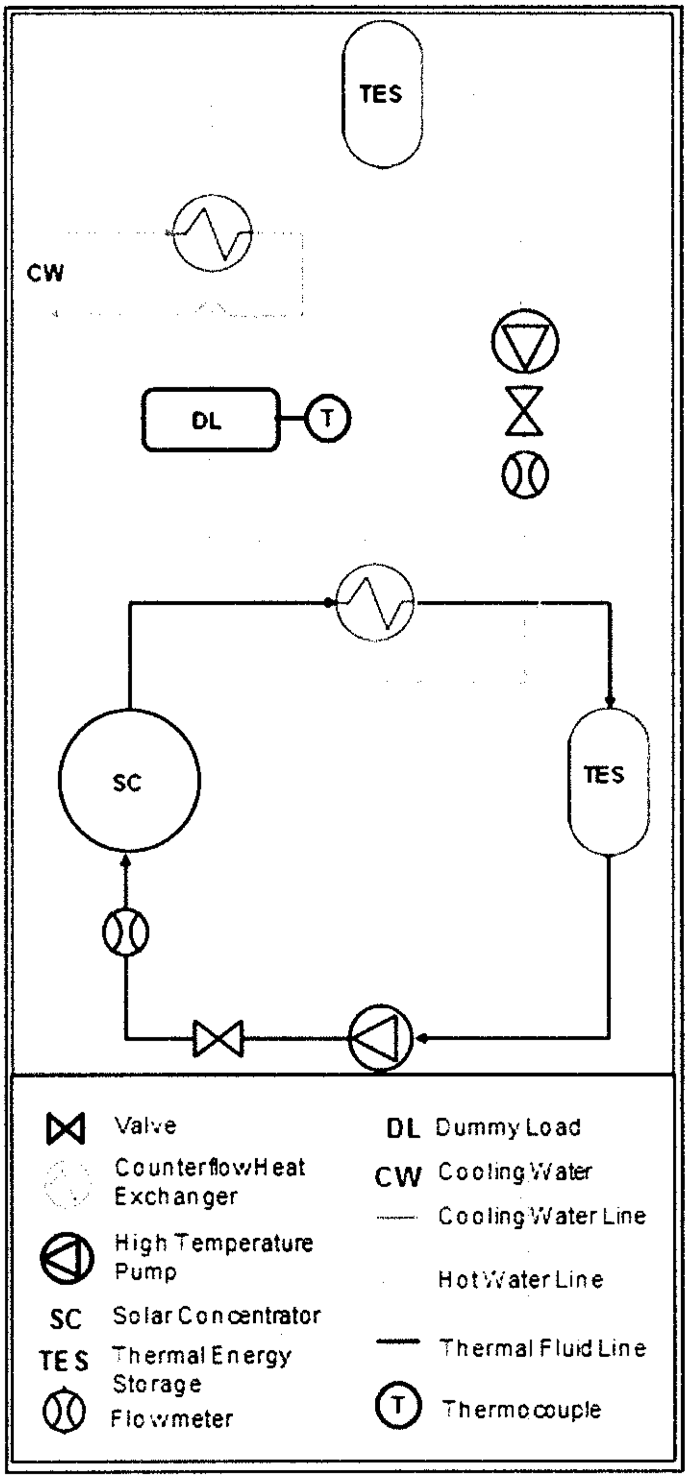


Figure E.1 The set-up of the system

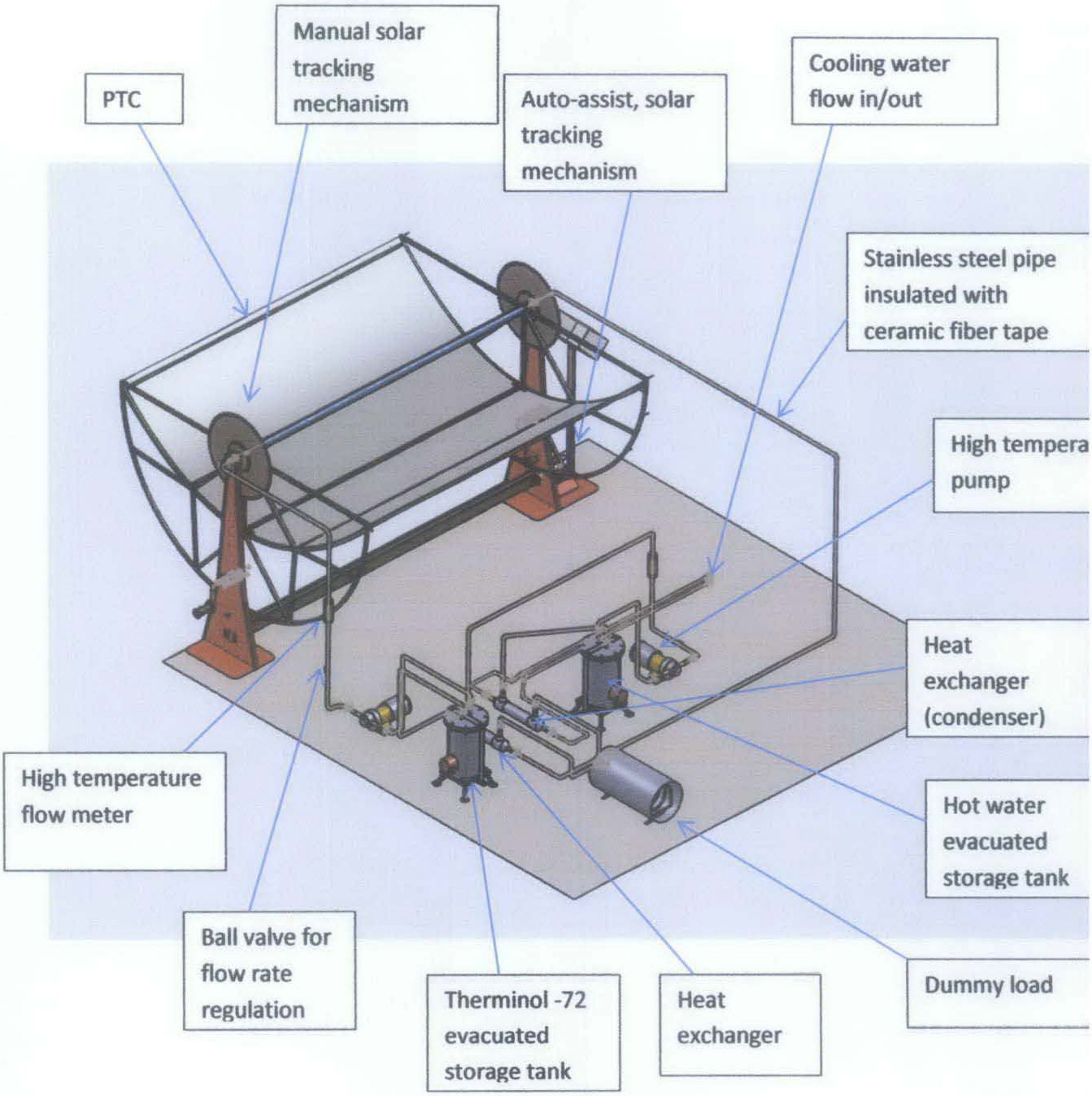
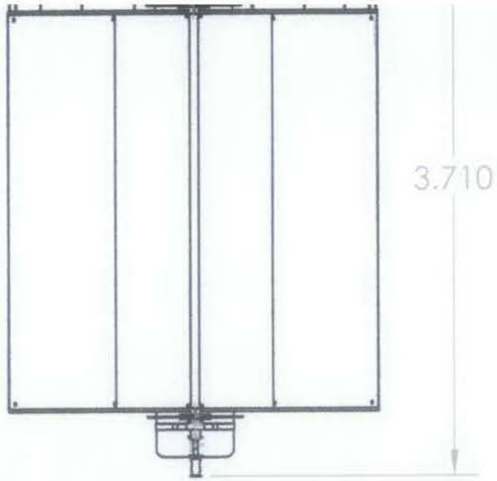
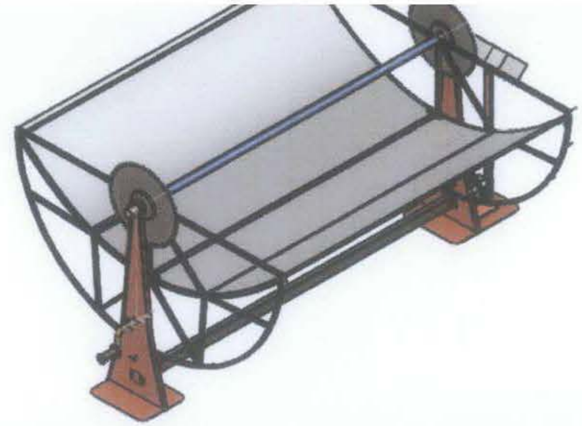
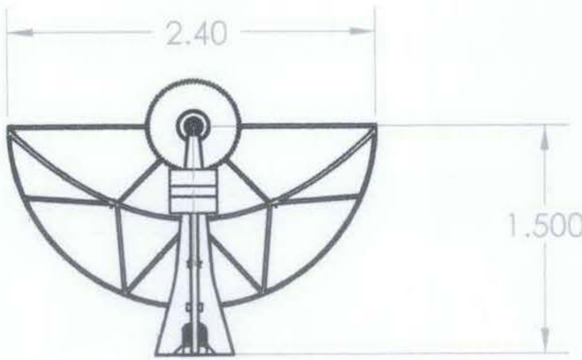


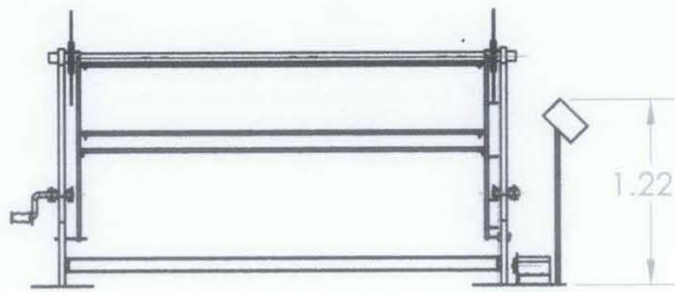
Figure E.2 The concept modelling of the system

APPENDIX 6

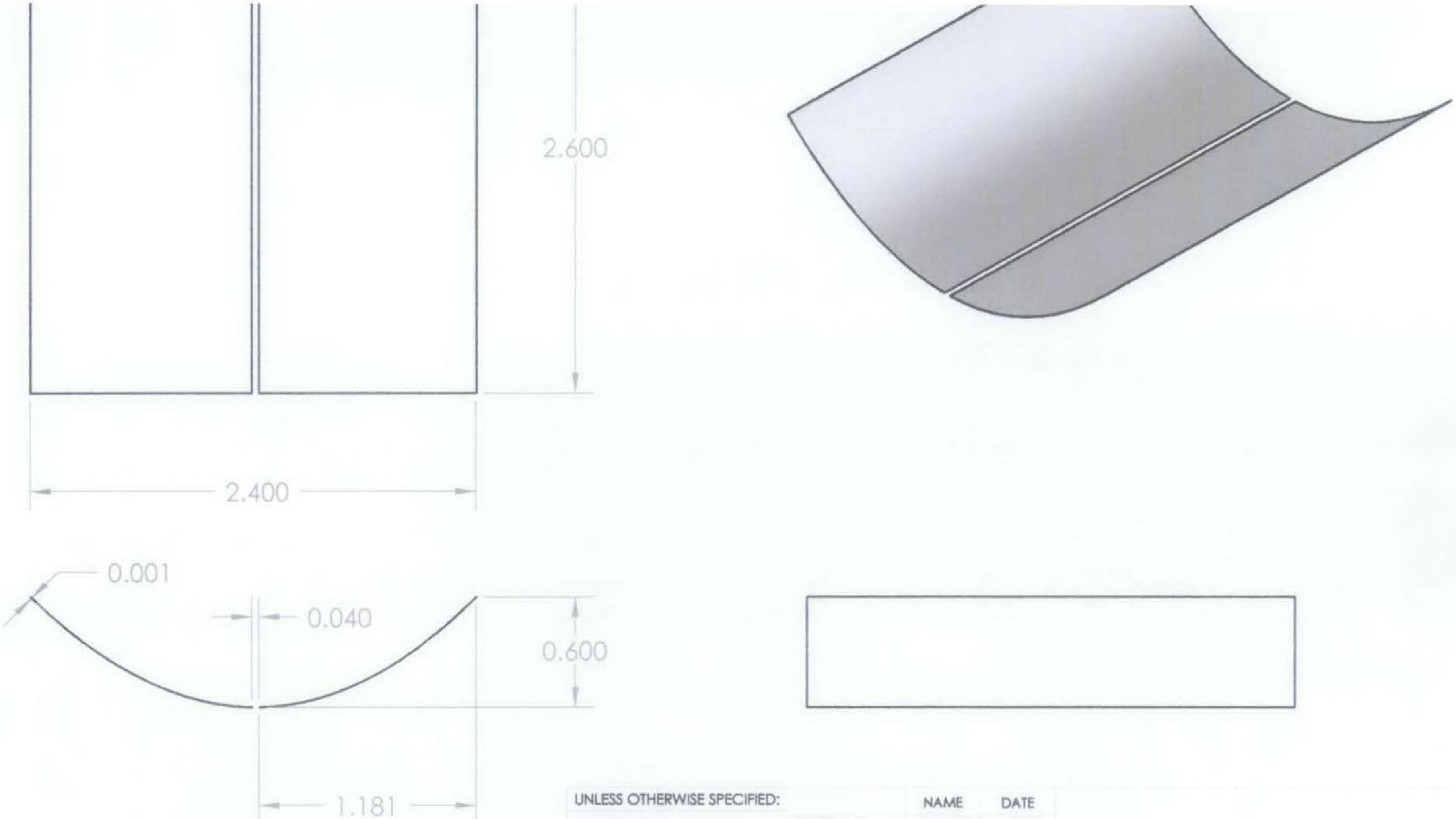








UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			PTC Assembly
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 · DWG. NO. A-1 · REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:50 WEIGHT: SHEET 1 OF 1



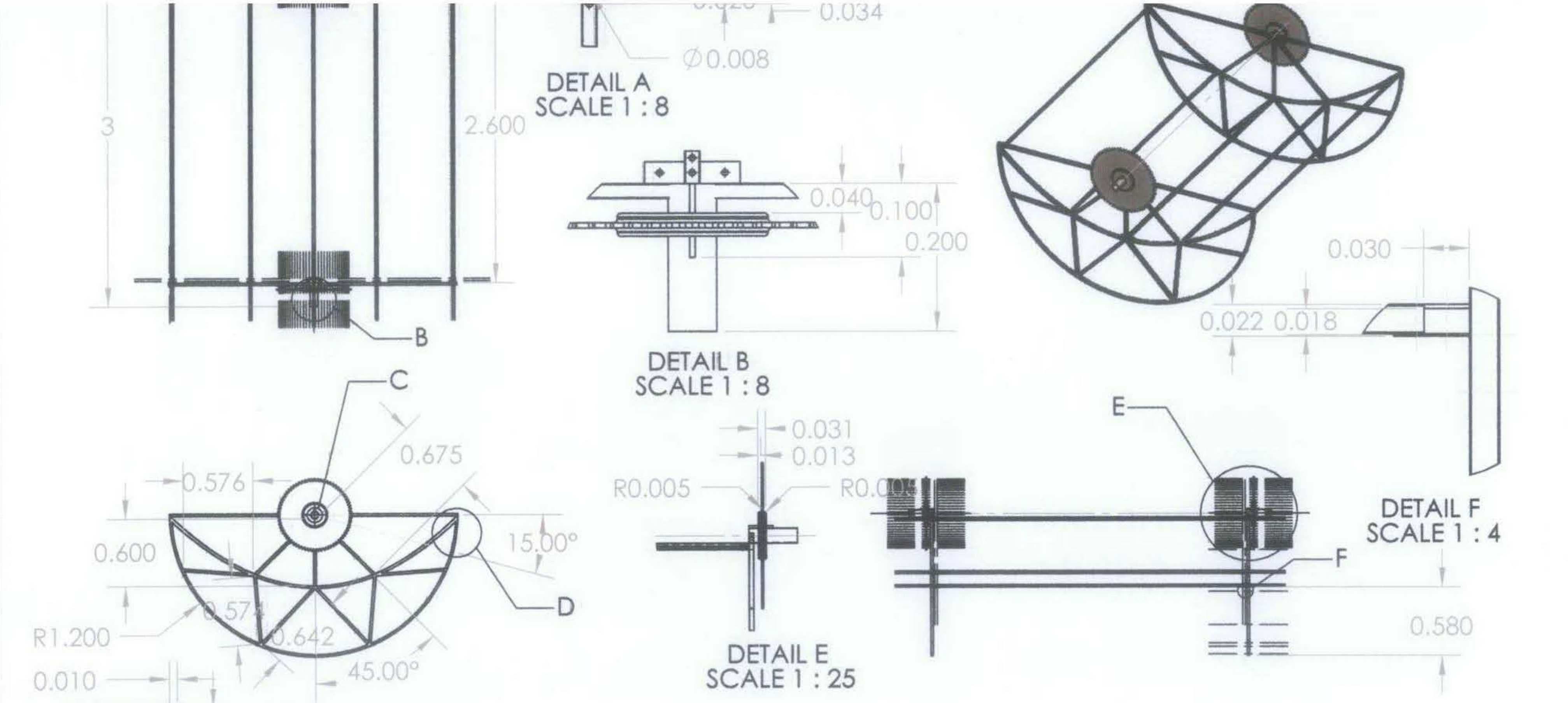
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ	
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Aluminum	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

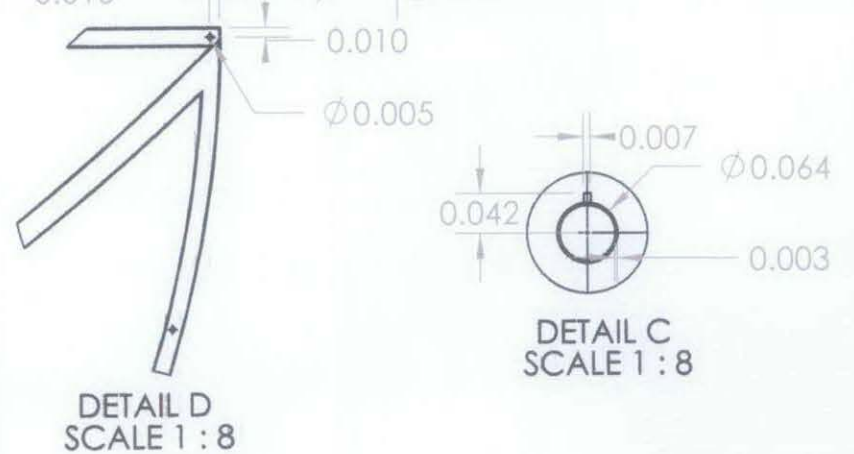
TITLE:

[PTC] Reflective Aluminum Sheet

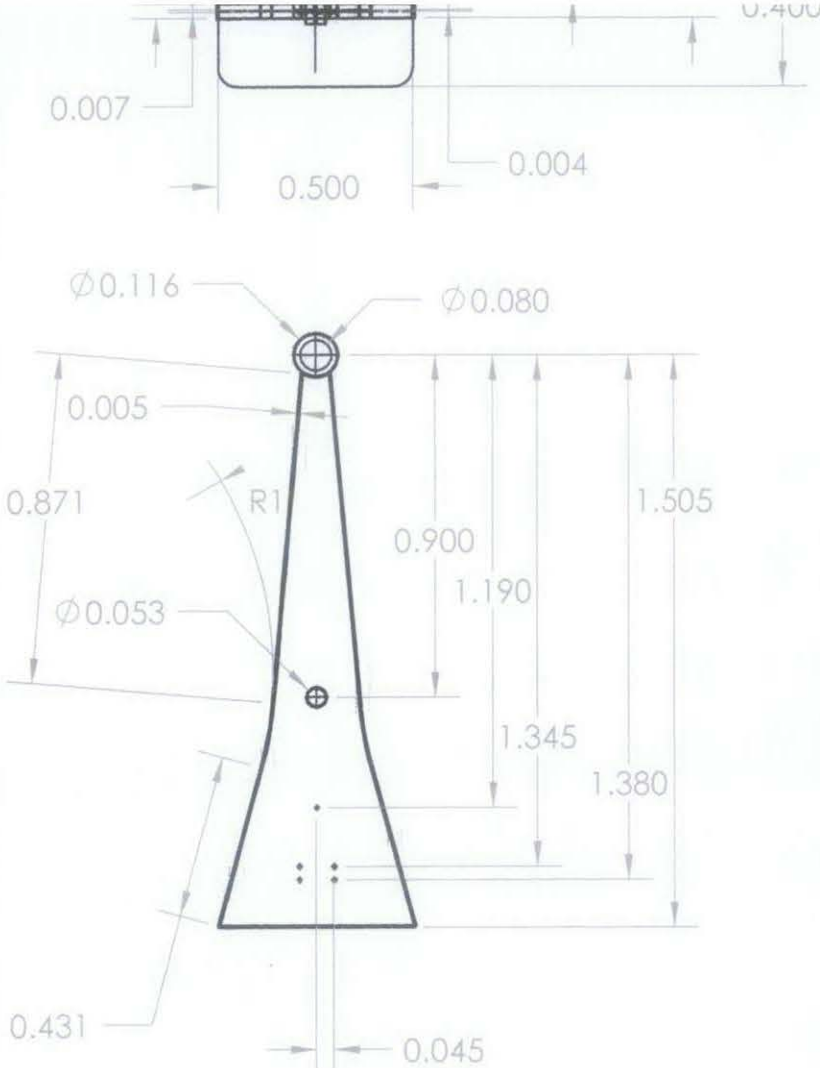
SIZE	DWG. NO.	REV
A4	A-2	B

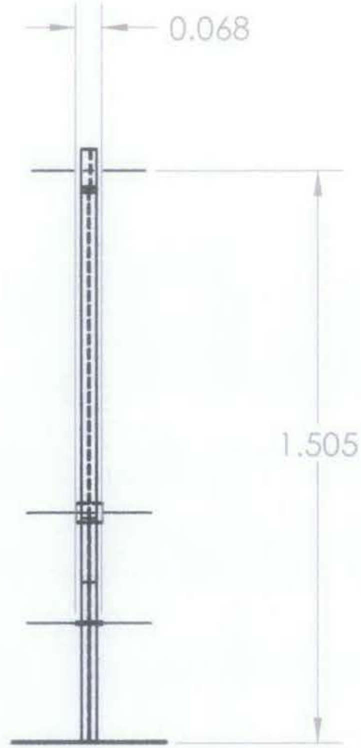
SCALE: 1:33.3 WEIGHT: SHEET 1 OF 1



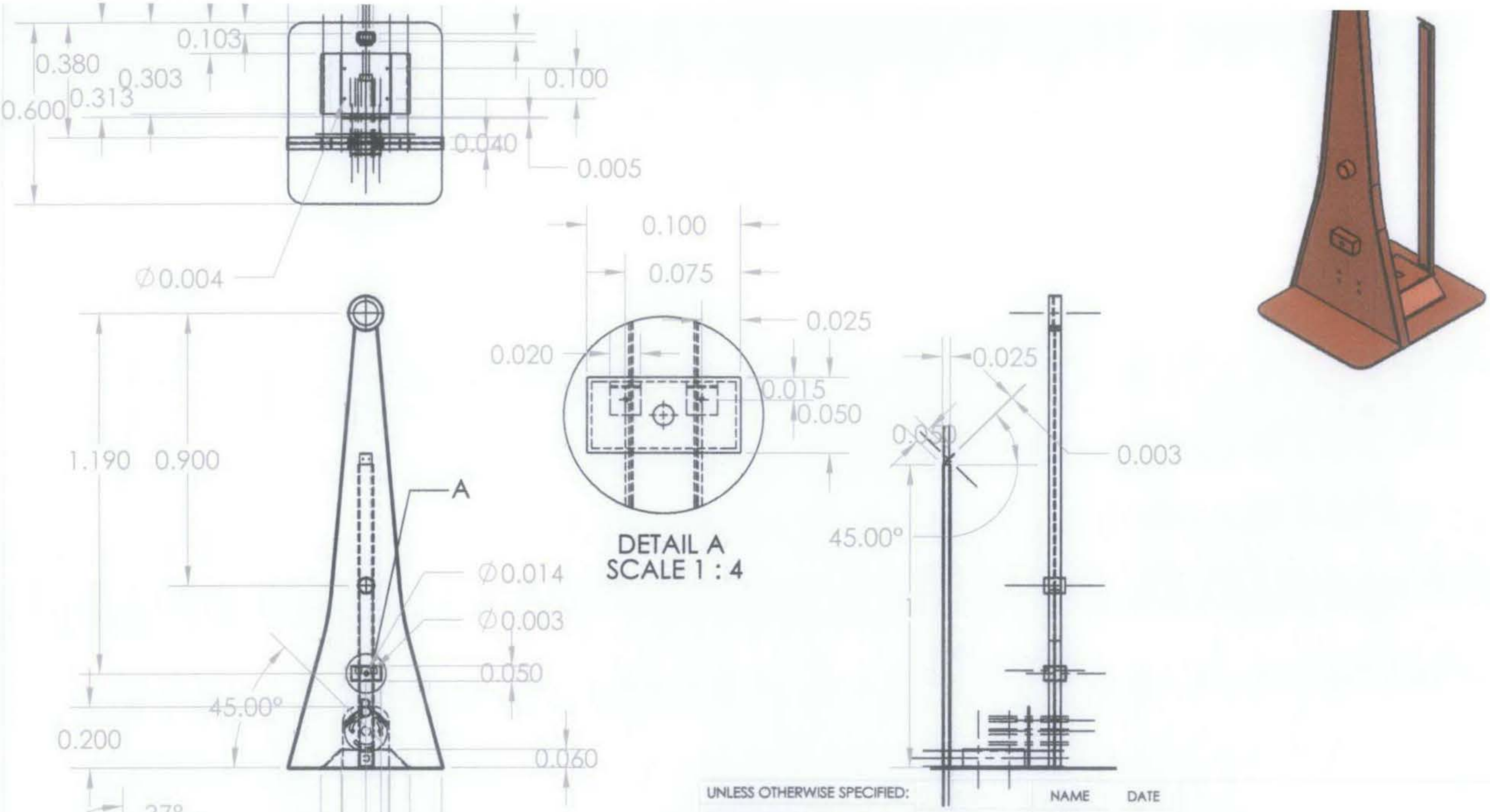


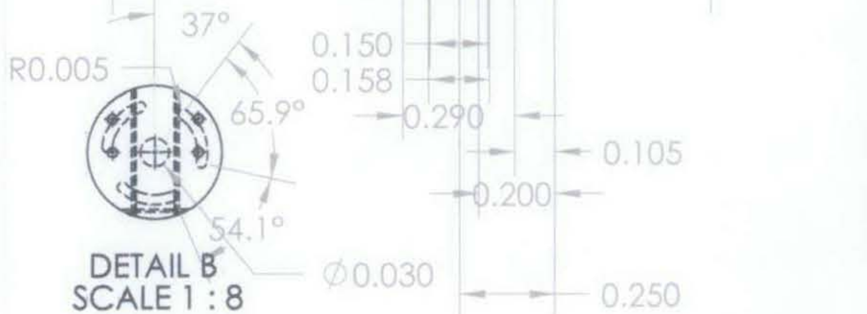
		NAME	DATE	
UNLESS OTHERWISE SPECIFIED:				
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		
	CHECKED			TITLE:
	ENG APPR.			PTC Frame with 72-teeth ANSI 40 sprocket
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Stainless Steel	COMMENTS:			SIZE A4	DWG. NO. A-3	REV C
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:50 WEIGHT:	SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			PTC Saddle Manual Side
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Steel	COMMENTS:			SIZE A4 DWG. NO. A-4 REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:20 WEIGHT: SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN METRES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

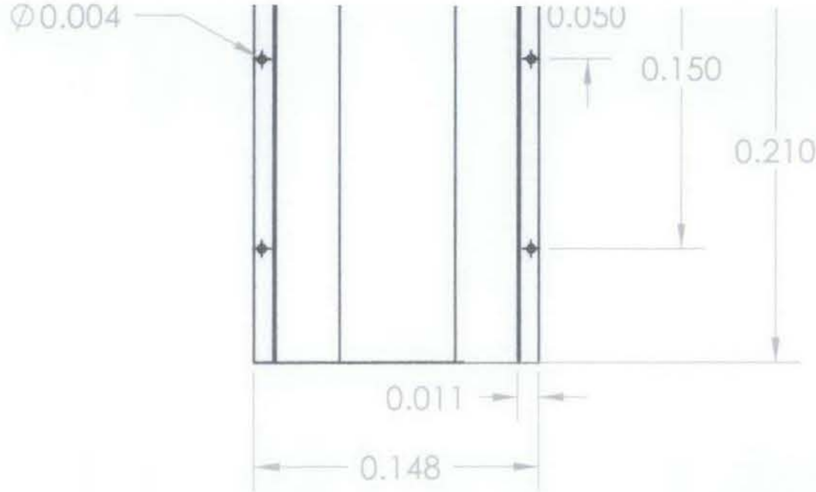
	NAME	DATE
DRAWN	SSJ	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

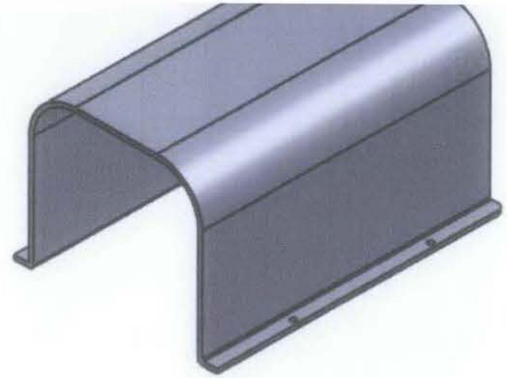
TITLE:

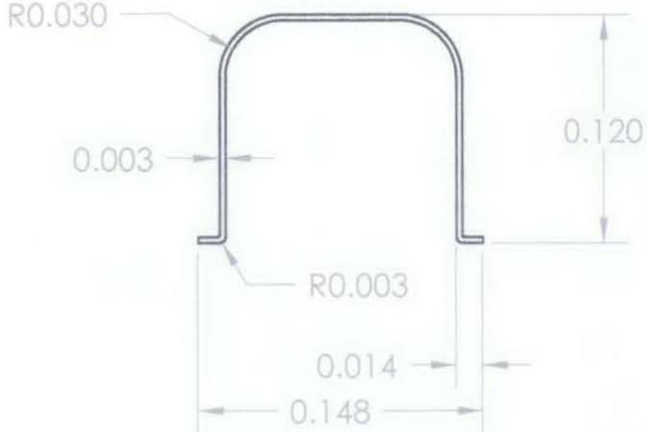
PTC Assembly

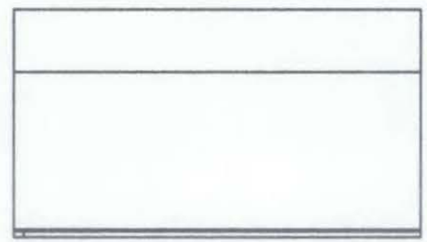
SIZE	DWG. NO.	REV
A4	A-5	B

SCALE: 1:20 WEIGHT: SHEET 1 OF 1

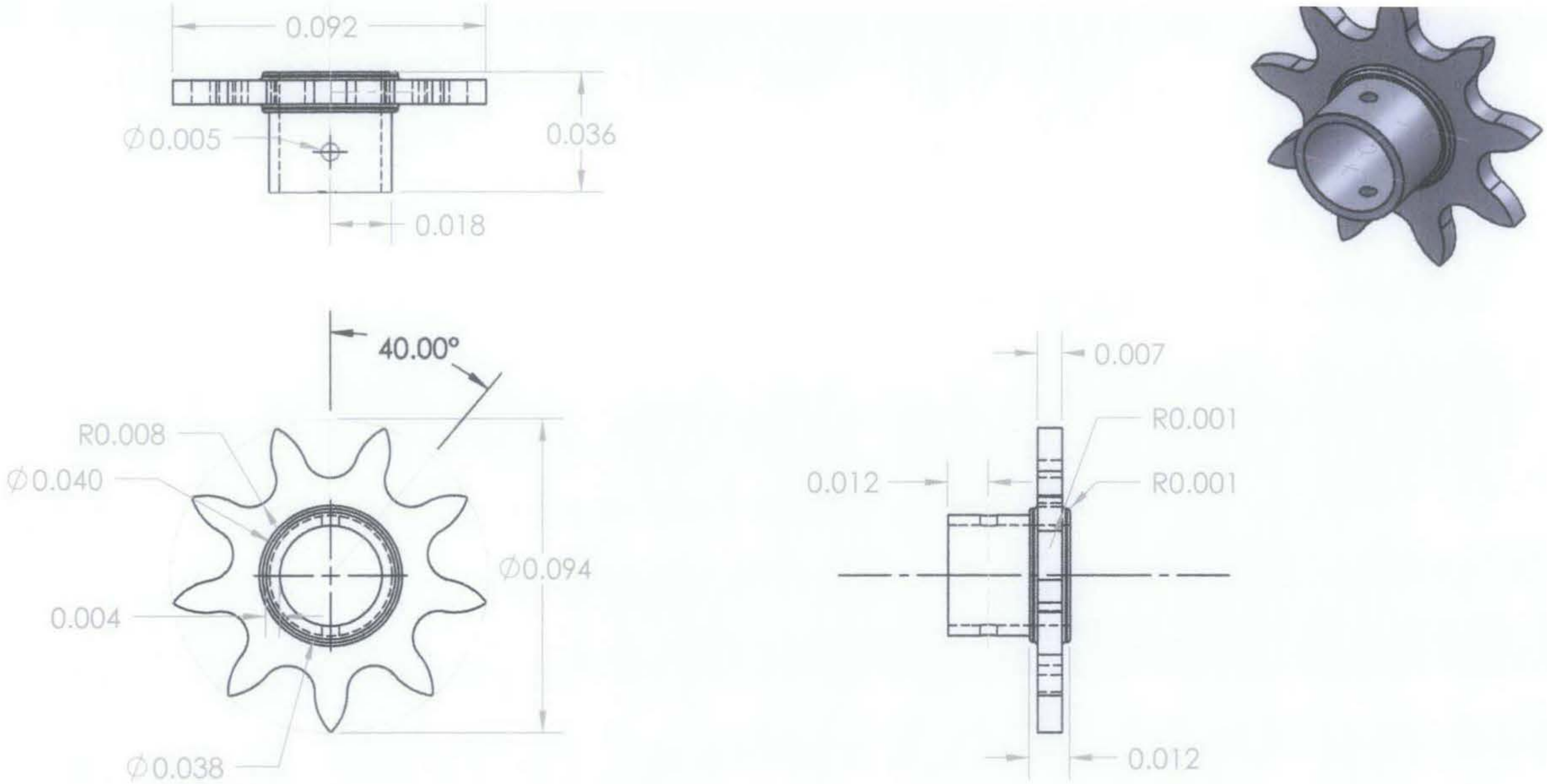




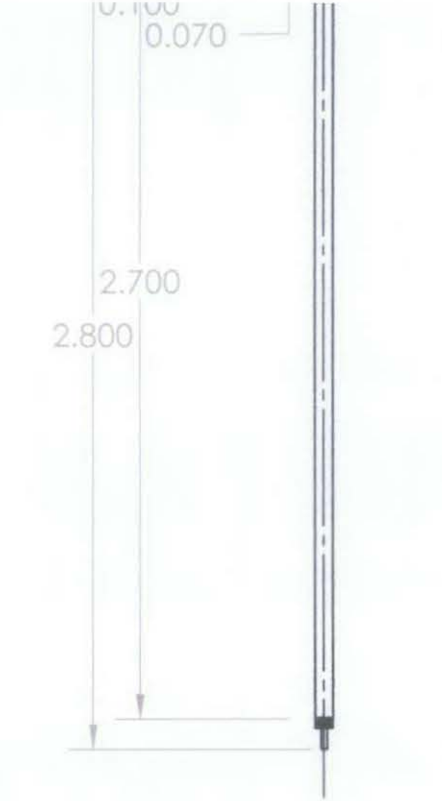


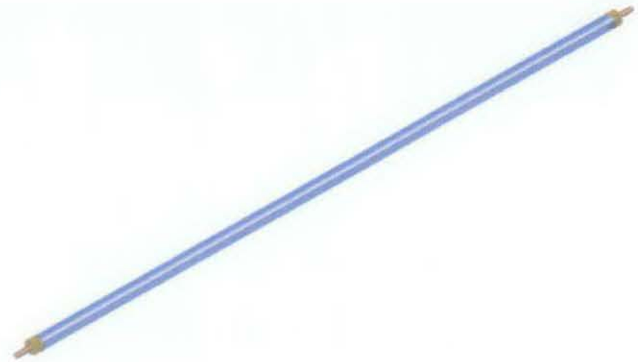


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			[PTC] Electric Motor Cover
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 3mm Steel Plate	COMMENTS:			SIZE A4 DWG. NO. A-6 REV C
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT: SHEET 1 OF 1



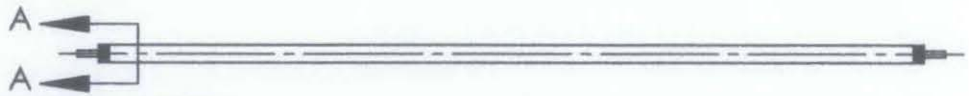
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN METERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	SSJ			9-Teeth driving sprocket for ANSI 40 chain	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: Stainless Steel	DWG NO. A-7	





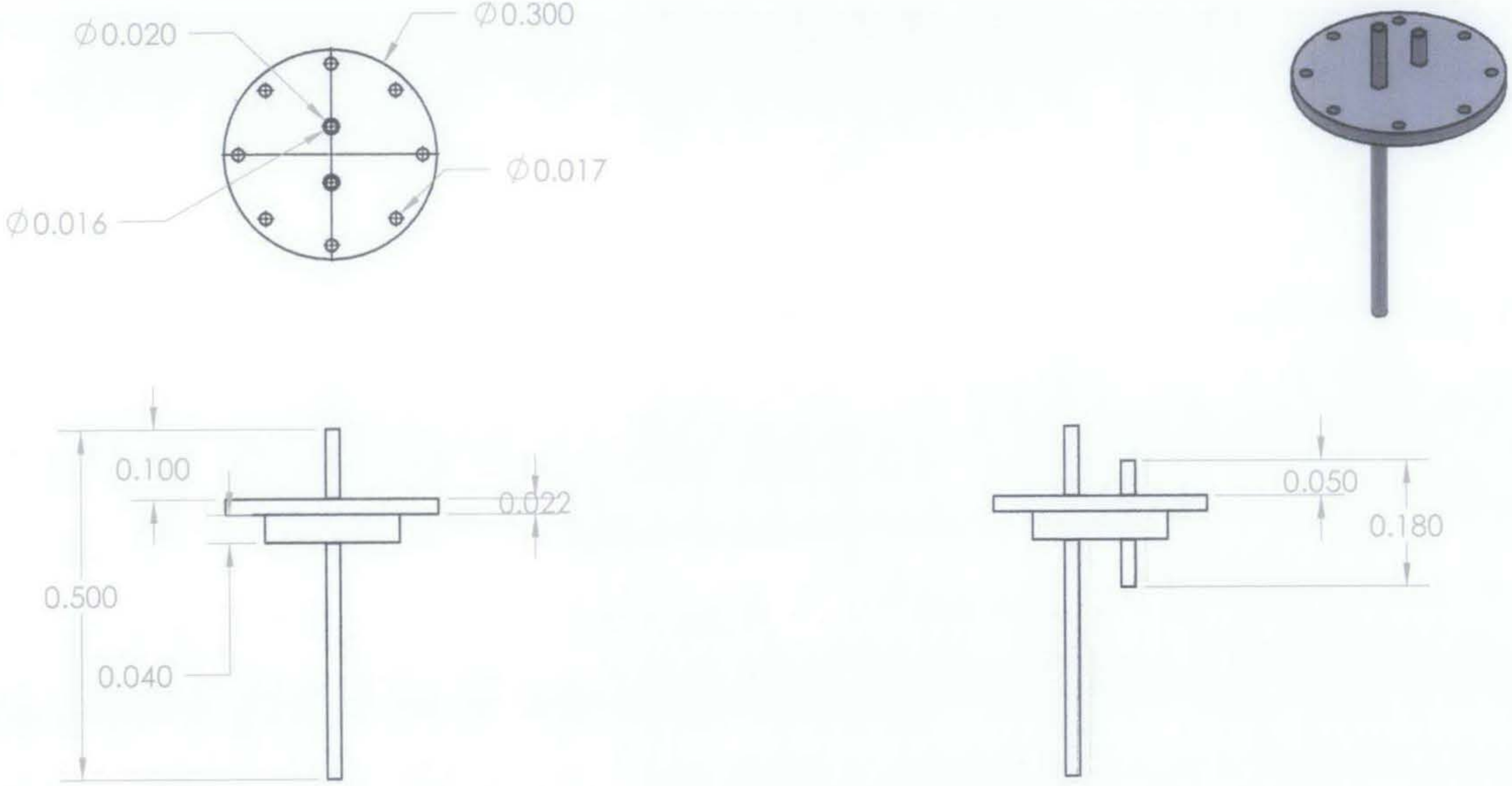
DETAIL B
SCALE 1 : 2

SECTION A-A
SCALE 1 : 4

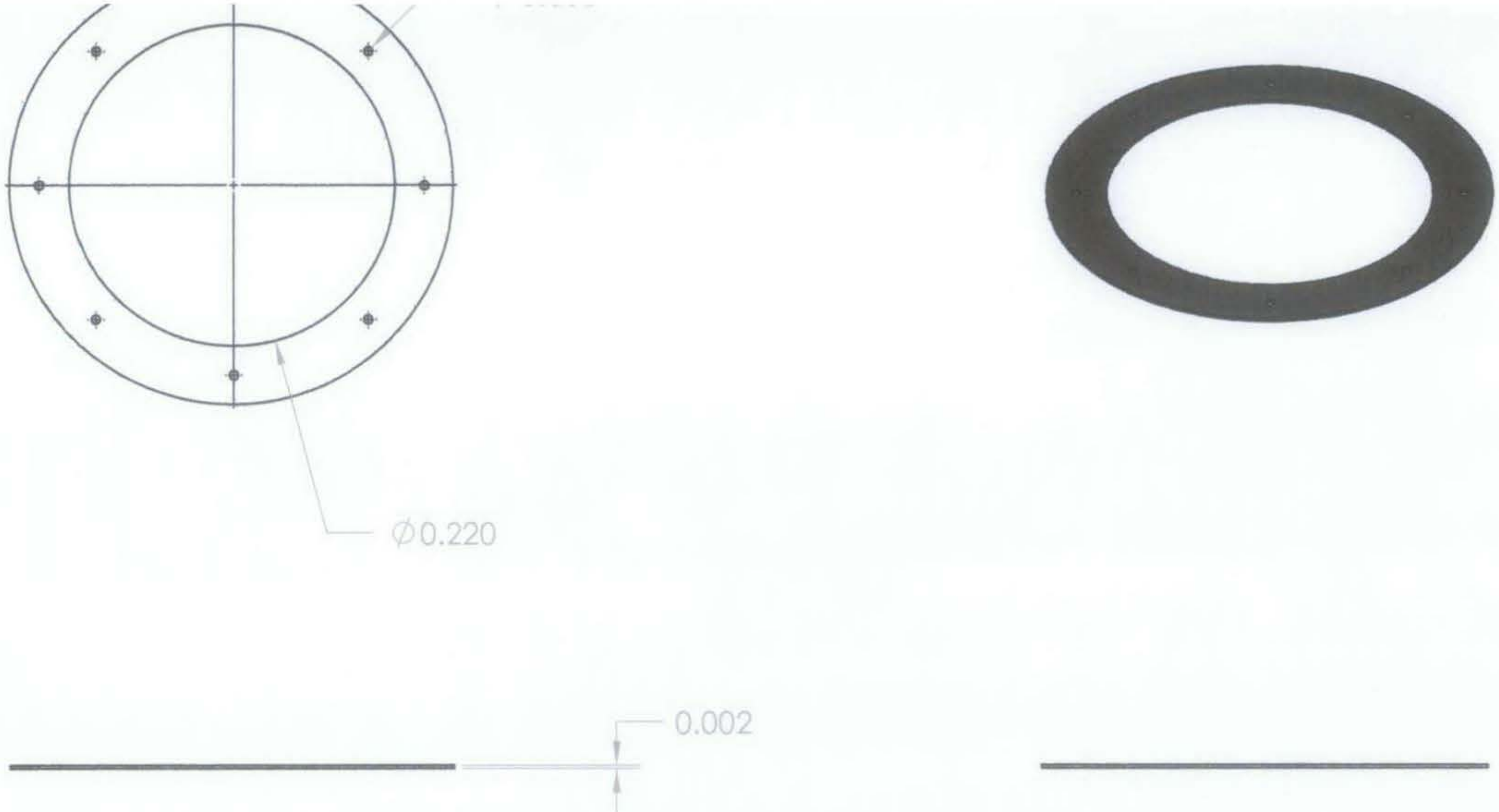


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			SOLTECH Evacuated Tube
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 — DWG. NO. A-8 — REV A
FINISH	Based on existing SOLTECH Evacuated Tube			
DO NOT SCALE DRAWING				SCALE: 1:25 — SHEET 1 OF 1

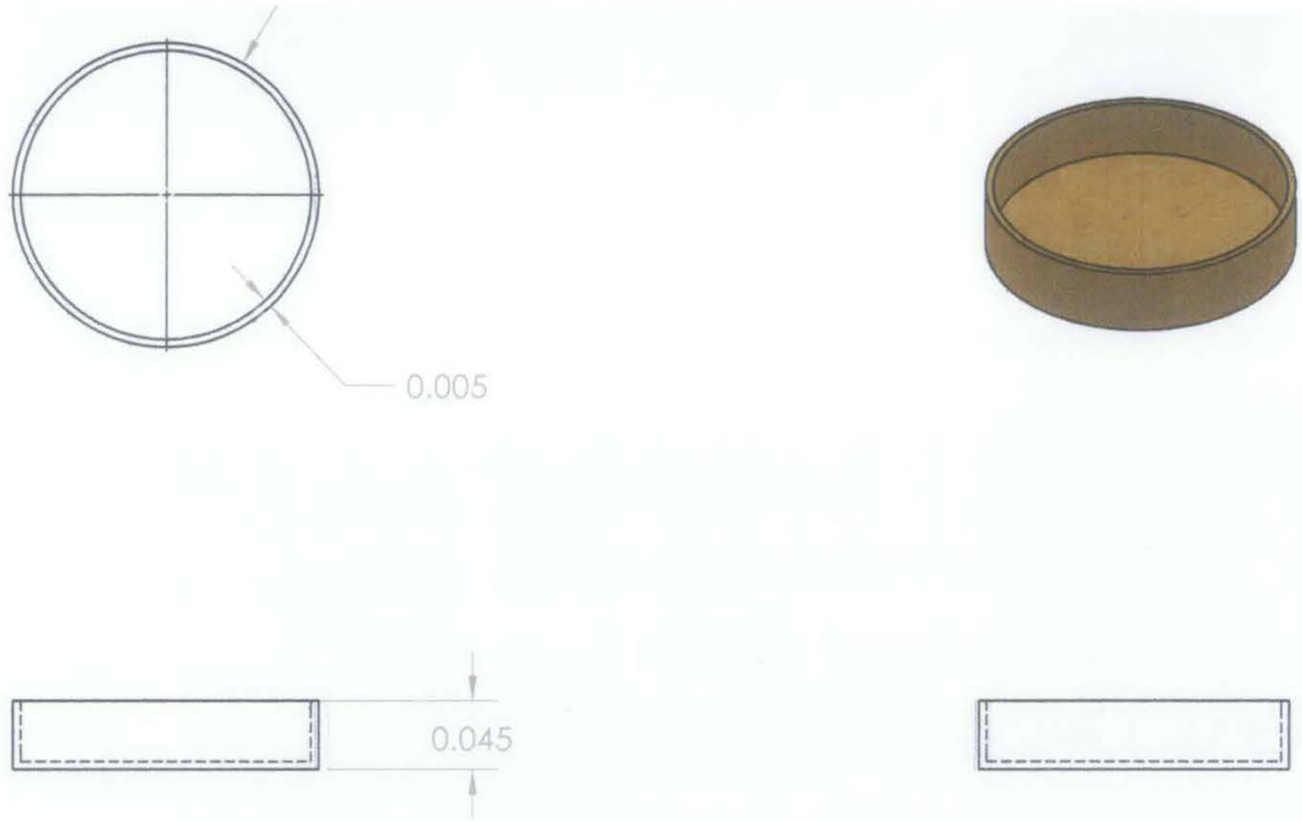
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		
	CHECKED			TITLE:
	ENG APPR.			ANSI Chain No. 40
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 DWG. NO. A-9 REV B
FINISH	Set 1 - 92 links Set 2 - 43 links			
DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT: SHEET 1 OF 1



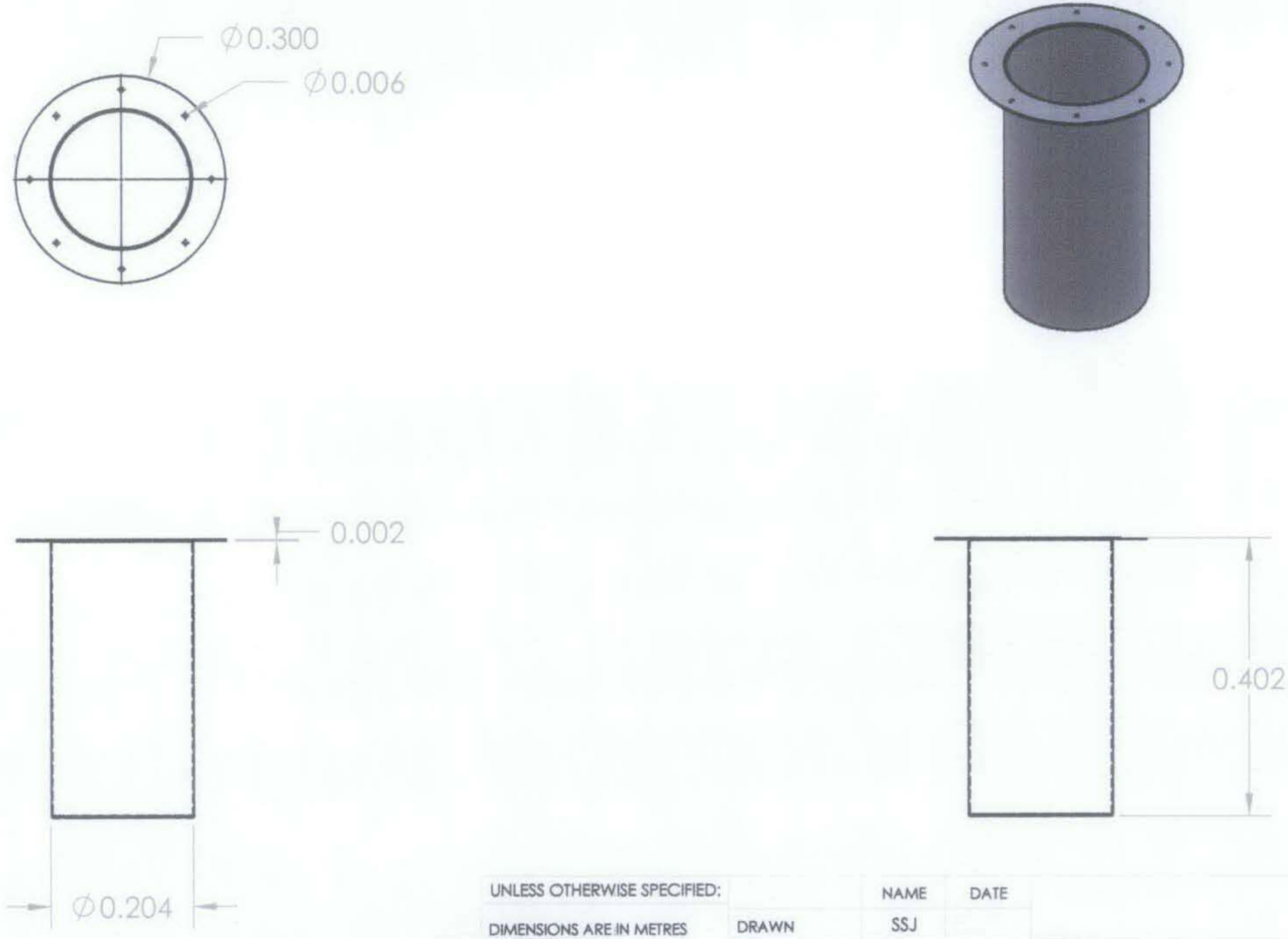
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			TES Cap
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 · DWG. NO. B-1 · REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10 WEIGHT: · SHEET 1 OF 1



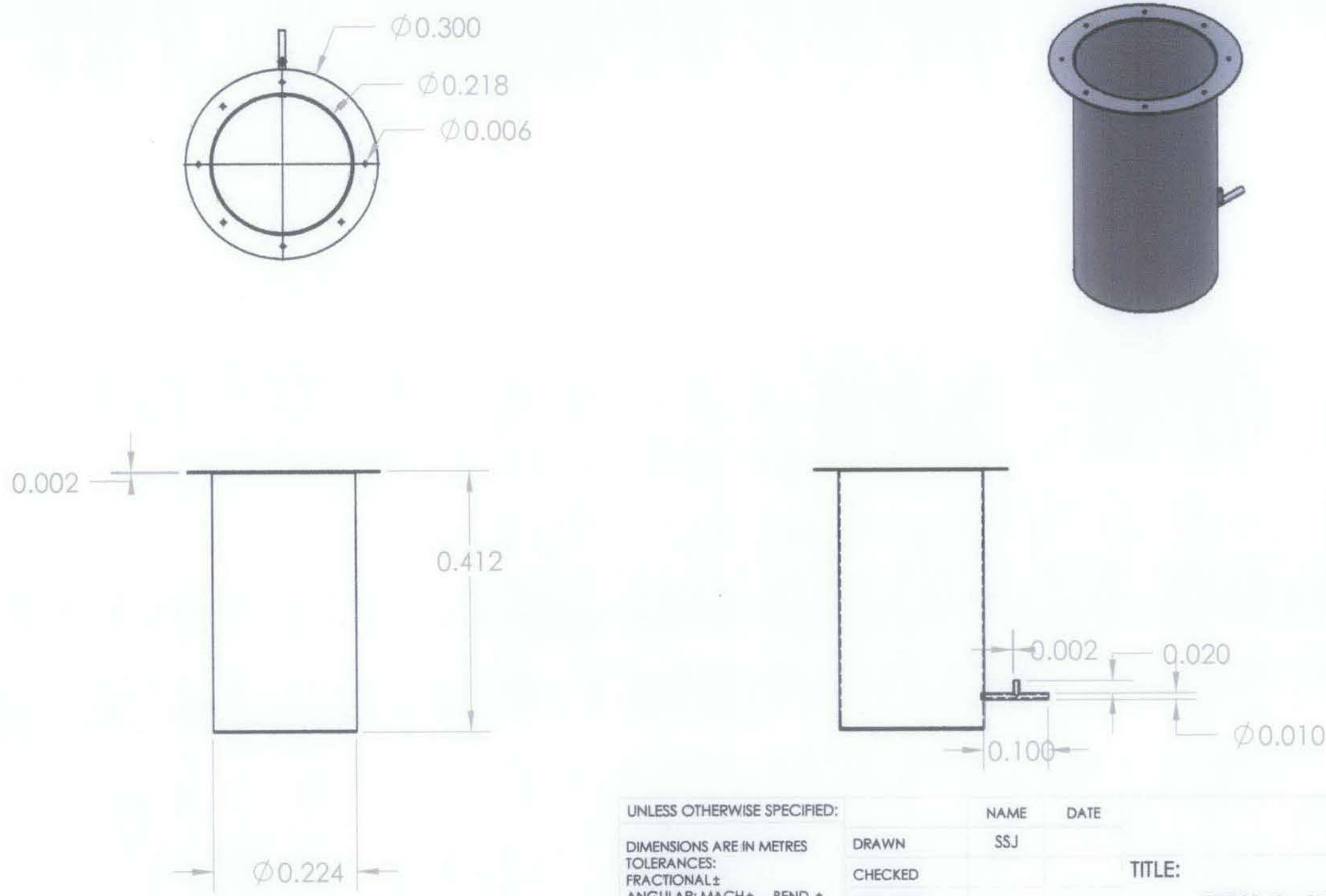
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE: [TES] Cork/ Metal Gasket
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE **A4** DWG. NO. B-2 REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT: SHEET 1 OF 1



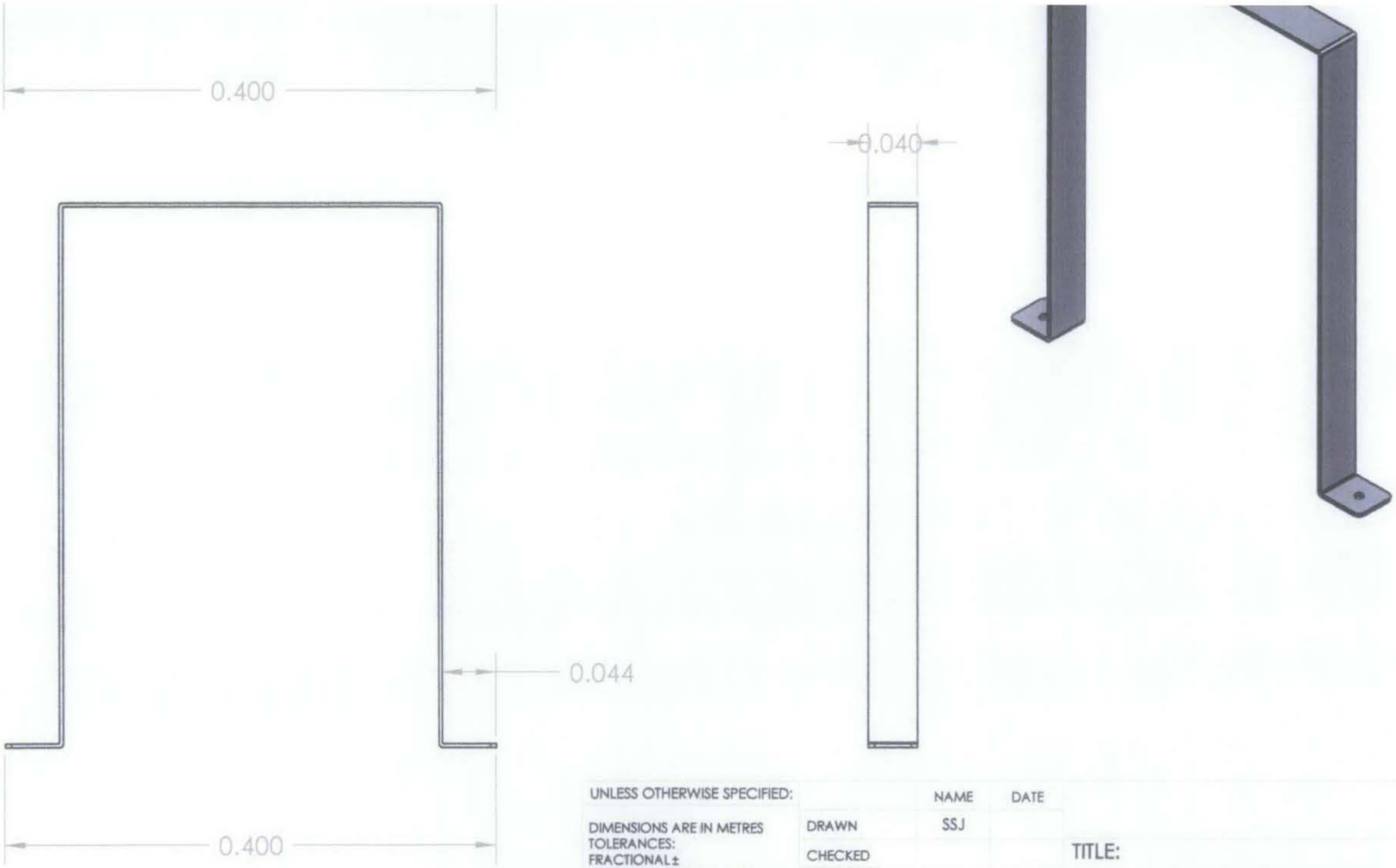
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			[TES] Cork Insulator
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 DWG. NO. B-3 REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			[TES] Inside Container
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 · DWG. NO. B-4 · REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10 WEIGHT: · SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			[TES] Outside Housing
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 · DWG. NO. B-5 · REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10 WEIGHT: · SHEET 1 OF 1

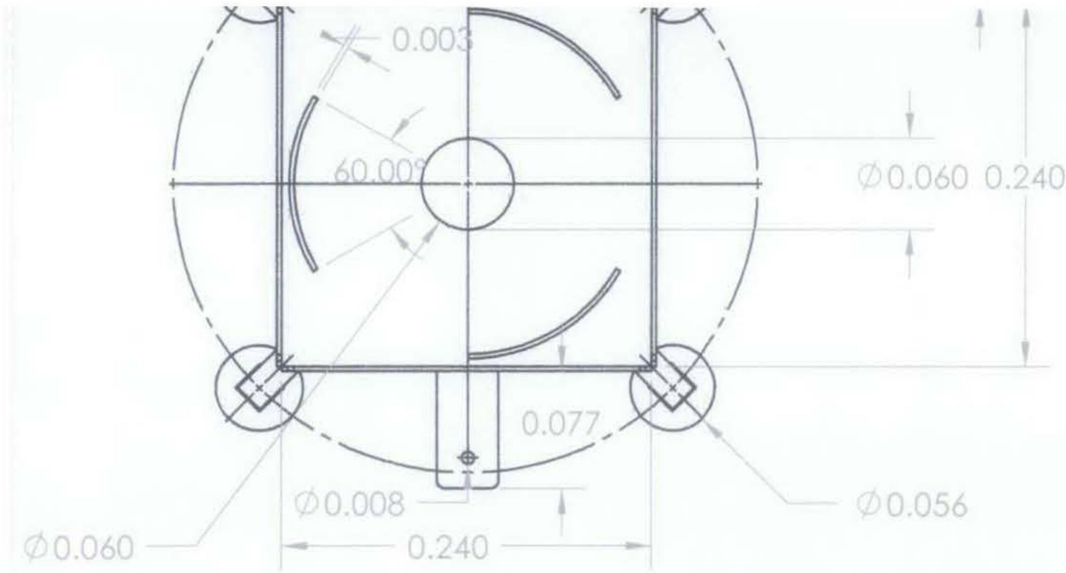


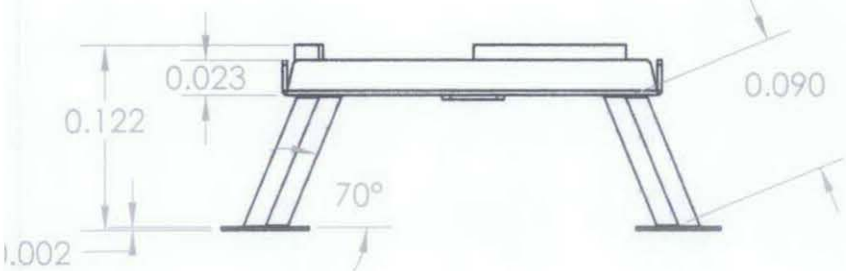
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ	
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

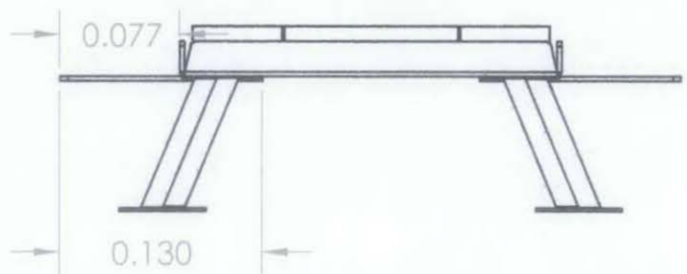
TITLE: [TES] Holding Bar

SIZE	DWG. NO.	REV
A4	B-6	B

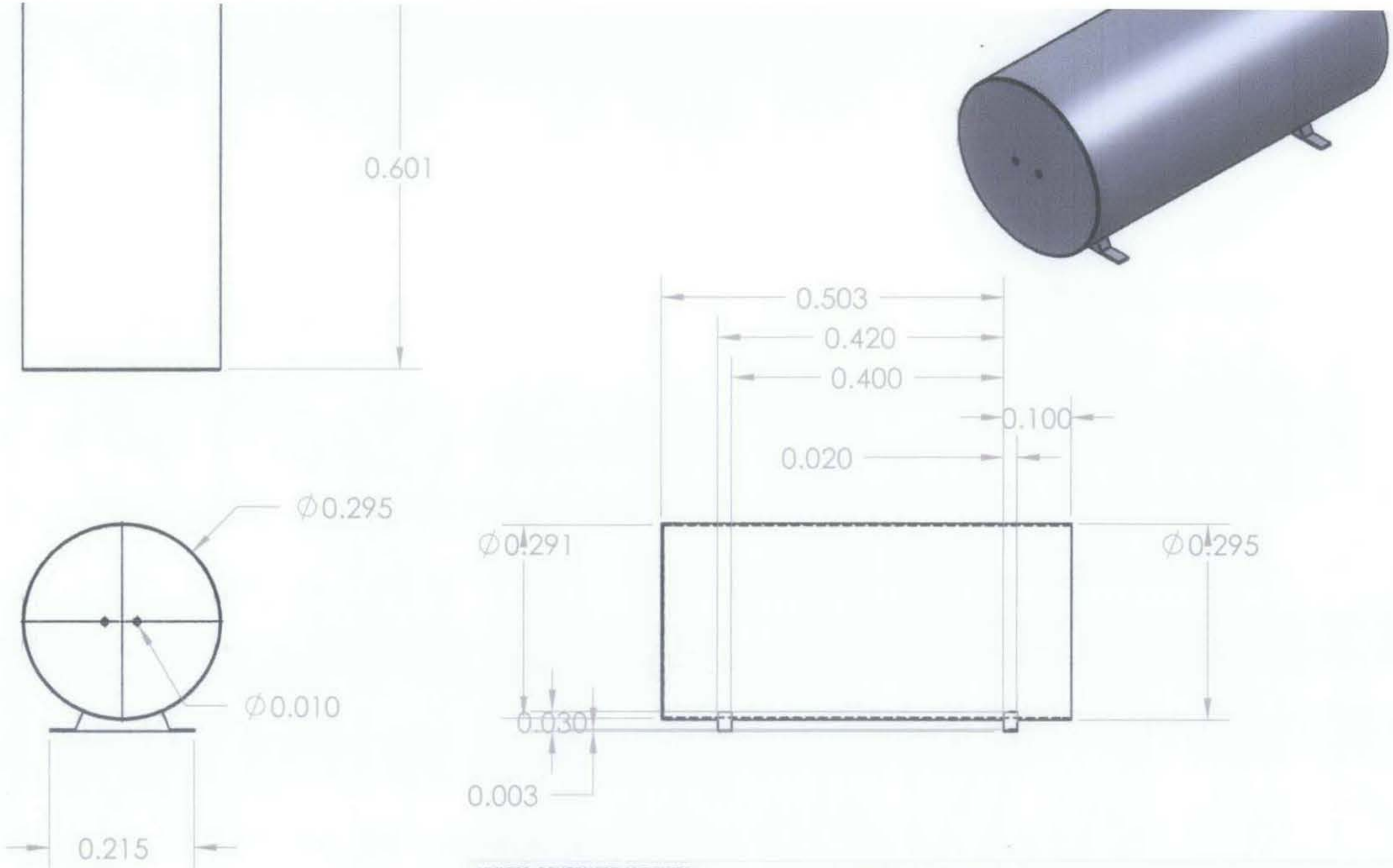
SCALE: 1:5 WEIGHT: SHEET 1 OF 1



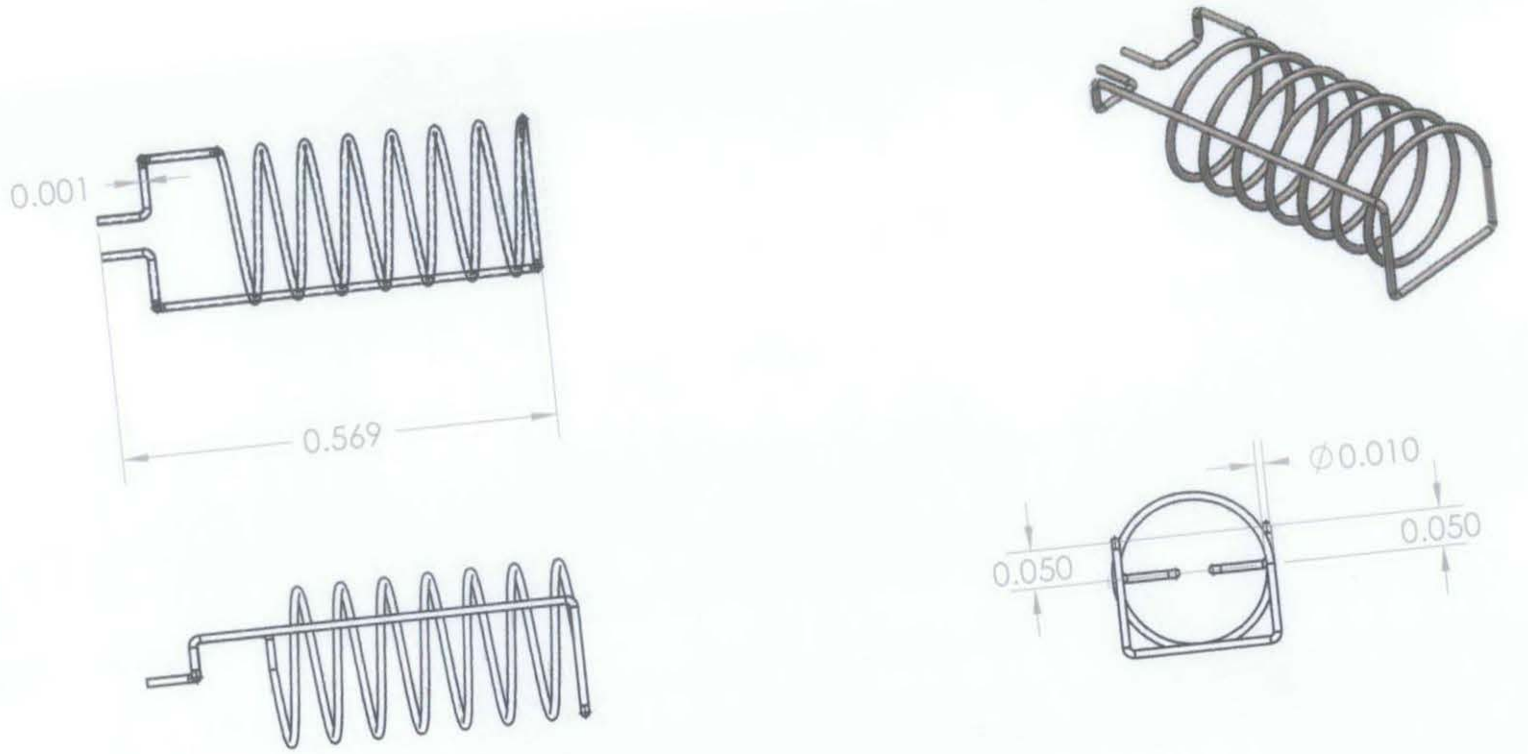




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		
	CHECKED			TITLE: [TES] Mounting Stand
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 · DWG. NO. B-7 · REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:5 · WEIGHT: · SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ		TITLE:
	CHECKED			Dummy Load Housing
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A4 DWG. NO. C-1 REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN METRES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	SSJ	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

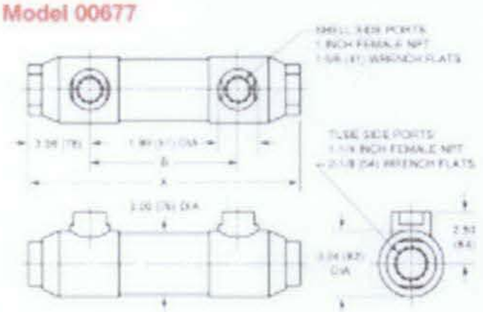
TITLE:
Dummy Load Heating Coil

SIZE **A4** DWG. NO. C-2 REV B

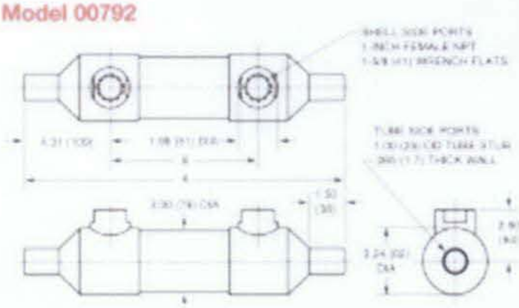
SCALE: 1:10 WEIGHT: SHEET 1 OF 1

APPENDIX 7

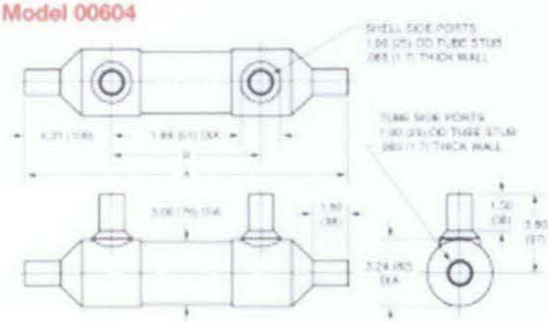
Model 00677

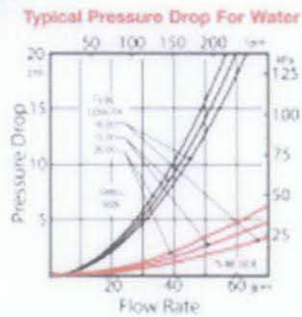


Model 00792



Model 00604

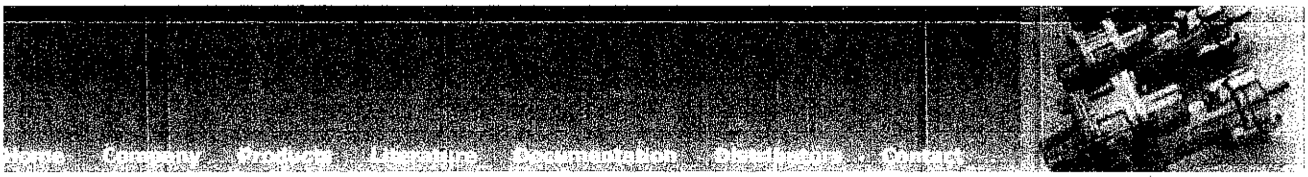




Tube Count	Tube Length in (mm)	Model #	Fitting Type: Shell Side NPT	Fitting Type: Shell Side Tube Stub	Fitting Type: Tube Side NPT	Fitting Type: Tube Side Tube Stub	A in (mm)	B in (mm)	Weight Empty lb (kg)	Transfer Area ft² (m²)
253	10.00 (254)	00677-1	•		•		13.50 (343)	7.38 (187)	11.2 (5.1)	6.51 (.60)
		00792-1	•			•	16.00 (406)			
		00604-1		•		•	16.00 (406)			
	15.00 (381)	00677-2	•		•		18.50 (470)	12.38 (314)	13.6 (6.2)	[illegible]
		00792-2	•			•	21.00 (533)			
		00604-2		•		•	21.00 (533)			
	20.00 (508)	00677-3	•		•		23.50 (597)	17.38 (411)	16.1 (7.3)	13.41 [illegible]
		00792-3	•			•	26.00 (660)			
		00604-3		•		•	26.00 (660)			

Selected Heat Exchanger

APPENDIX 8



Liquiflo
Chemical Processing Pumps

Max® Series Gear Pumps

ome / Gear Pumps / Max-Series / **M6**

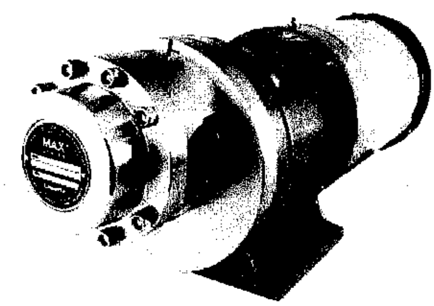
Model M6

High Pressure Gear Pump

316 SS | Titanium

Sealed | Mag-Drive

Port Connections	**1" NPT/BSPT** **1" FLG***
Max Flow Rate	**12.2 GPM; 46.2 LPM**
Max Diff. Pressure	**350 PSI; 24.1 BAR**
Max Discharge Pressure	**500 PSIG; 34.5 BARG ****
Max Viscosity	**100,000 CPS (mPas)**
Max Temperature	**500 °F; 260 °C**
Min Temperature	**-40 °F; -40 °C**
Max Speed	**1800 RPM**
NPSHR @ Max Speed	**5 FT; 1.5 M**
Lift (Dry) @ Max Speed	**7 FT; 2.1 M**
Weight (without motor)	
Sealed, Close-Coupled	**54 LBS; 24.5 KGS**
Mag, Close-Coupled	**54 LBS; 24.5 KGS**



Model M6 Sealed or Mag-Drive Close-Coupled

Liquiflo **Max-Series Gear Pumps** are manufactured from **316 Stainless Steel** or **Titanium**, and are available in both **Sealed** and **Mag-drive** configurations. These pumps feature Helical gears and relieved wear plates for smoother and quieter operation and intrinsic reduction of gear separation forces. Their unique and durable design will assure extended life in high-pressure pumping applications.

ANSI 150# Flanges are standard; 300# RF Flanges are optional.
* For flanged pumps, pressure derating is required based on flange type and temperature.

Questions?
Contact us for your application needs

Performance Curves
M6 (pdf)

Dimensional Drawings
M5-M8 Sealed (pdf)

M5-M8 Mag-Drive (pdf)

Product Manuals
Max-Series Sealed (pdf)

Max-Series Mag-Drive (pdf)

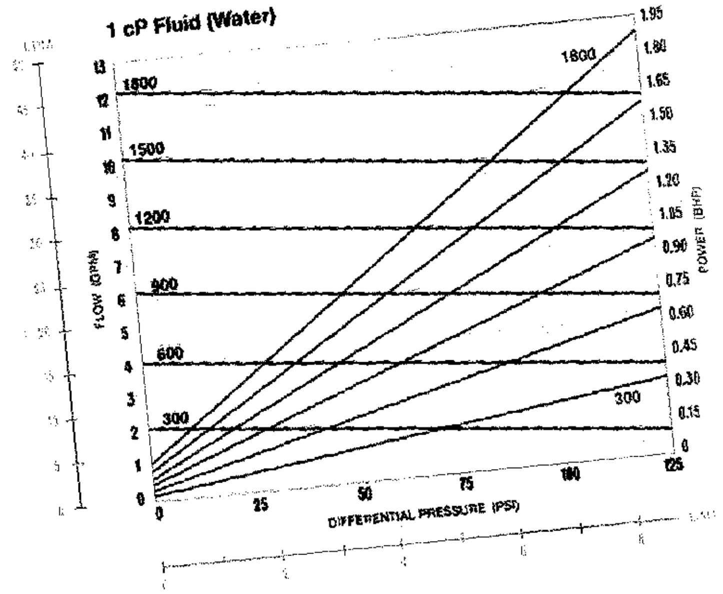
Model Coding
Max-Series (pdf)

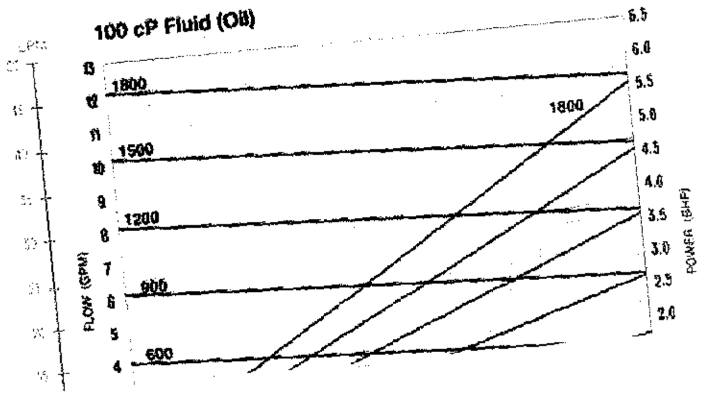
Bill of Materials

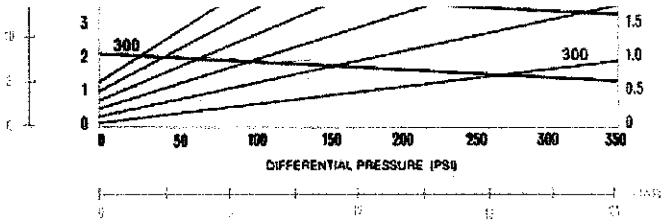
M6 Performance Curves

http://www.liquiflo.com/v2/gears/max

Max-Series (pdf)

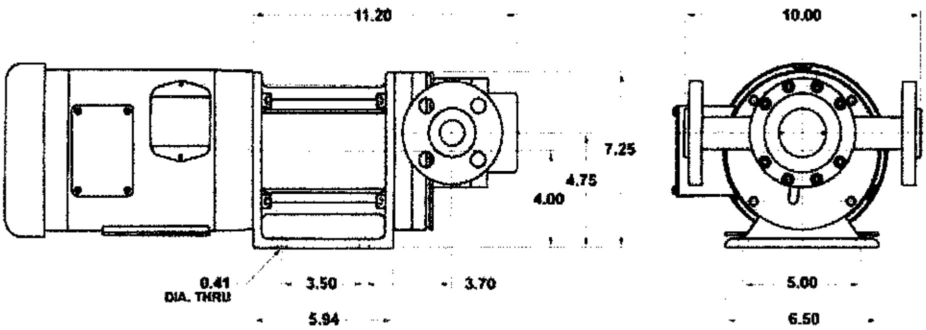




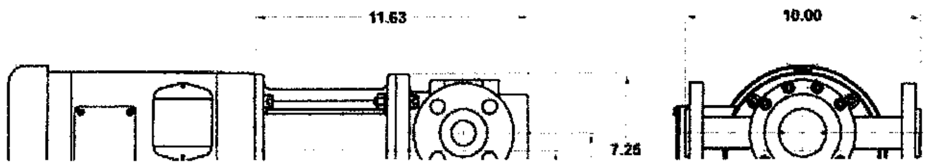


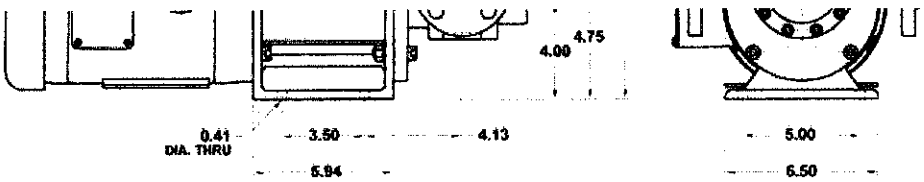
M6 Dimensional Drawings

46 Sealed with Flanged Ports, Close-Coupled



46 Mag-Drive with Flanged Ports, Close-Coupled



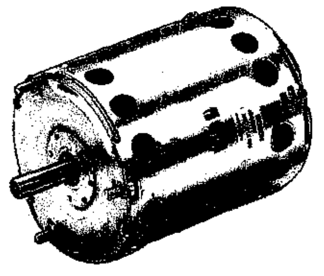


ome / Gear Pumps / Max-Series / **M6**

APPENDIX 9

.C. motors without transmission

GPA | 24 V 750 W



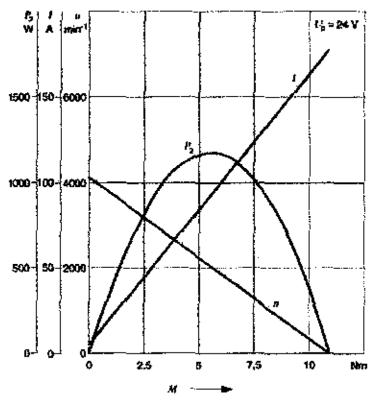
Technical data

Part number		**0 130 302 014**
Nominal voltage	U_N	24 V
Nominal power	P_N	750 W
Nominal current	I_N	40 A
Nominal speed	n_N	3300 min^{-1}
Nominal torque	M_N	2,2 Nm
Breakaway torque	M_A	11 Nm
Direction of rotation		L/R
Type of duty		S 1
Degree of protection		IP 10
Weight		approx. 3,80 kg

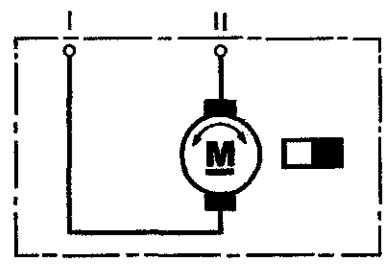
I = red, II = black.

Clockwise	(–) to I, (+) to II.
Counterclockwise	(+) to I, (–) to II.

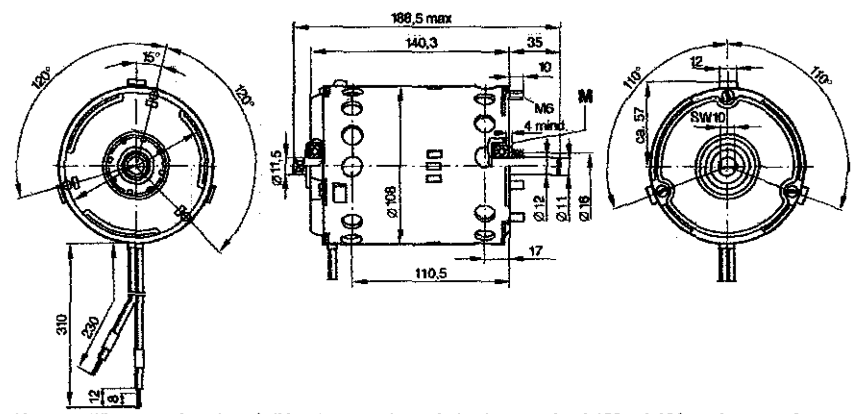
Characteristic curve



Connection diagram



Dimensional drawing

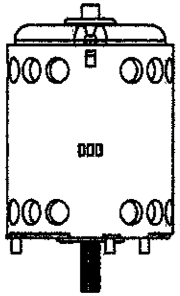


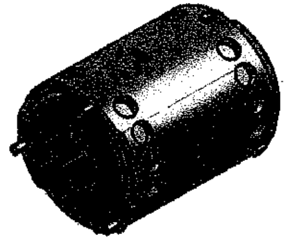
M When mounting, clamp ball-bearing inner ring with ring (part number 3 130 202 004, not in scope of delivery

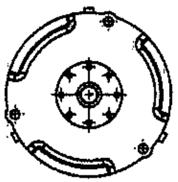
Robert Bosch GmbH
Automotive Aftermarket
Postfach 410960
76225 Karlsruhe
Germany

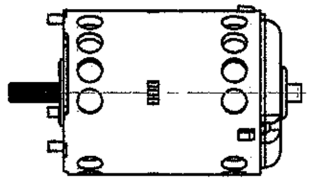
www.bosch-elektromotoren.de

BOSCH
Invented for life









		NAME	DATE
UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN METRES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	SSJ	
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

TITLE:

24 V DC Bidirectional Motor

SIZE	DWG. NO.	REV
A4	A-10	B

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

APPENDIX 10

Figure J.1 The sample of motor controller program

```
TRISA=%
TRISB=%
TRISC=%
TRISD=%

  DEFINE LCD_DREG PORTD
  DEFINE LCD_DBIT
  DEFINE LCD_RSREG PORTE
  DEFINE LCD_RSBIT
  DEFINE LCD_EREG PORTE
  DEFINE LCD_EBIT
  ADCON:=

  dta VAR PORTC.
  clk VAR PORTC.

  cmdt CON %
  cmdh CON %

  result VAR WORD
  chksu VAR BYTE
  cmd VAR WORD
  RHlir VAR WORD
  RHtc VAR WORD
  Temp VAR WORD
  DP VAR WORD

  TempDI VAR WORD
  Rchk VAR BYTE
  logE VAR WORD
  sigr VAR BIT
  wy VAR WORD
  wz VAR WORD
```